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U. S. DEPARTMENT OF AGRICULTURE,

OFFICE OF EXPERIMENT STATIONS,

A. C. TRUE, Director.

THE USE OF WATER IN IRRIGATION IN WYOMING

AND ITS RELATION TO

THE OWNERSHIP AND DISTRIBUTION OF THE NATURAL SUPPLY.

BY

B. C. BUFFUM, M. S.,

Professor of Agriculture and Horticulture, University of Wyoming, and
Vice-Director of Wyoming Agricultural Experiment Station.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1900.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Washington, D. C., February 27, 1900.

Sir: I have the honor to transmit herewith a paper by Prof. B. C. Buffum, of the University of Wyoming, on the use of water in irrigation in Wyoming and its relation to the ownership and distribution of the natural supply, and to recommend its publication as a bulletin of this Office.

This bulletin has been prepared under the supervision of Mr. Elwood Mead, expert in charge of the irrigation investigations of this Office, and supplies information on the subjects treated, with special reference to conditions existing in the State of Wyoming. The Office is now engaged in collecting similar data in a number of other States and Territories, with a view to a more comprehensive presentation of this matter in the future.

Respectfully,

A. C. True,
Director.

Hon. James Wilson,
Secretary of Agriculture.

LETTER OF SUBMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Irrigation Investigations,
Cheyenne, Wyo., January 3, 1900.

Sir: I have the honor to submit herewith a paper prepared by B. C. Buffum, professor of agriculture and horticulture in the University of Wyoming, on the use of water in irrigation in Wyoming. It describes his studies on this subject during the past nine years and gives his conclusions regarding certain measures and methods needed to secure the largest service from the available supply.

The investigations of Professor Buffum deal with the same problems as the more comprehensive studies of the duty of water made by the Office of Experiment Stations during the irrigation season of 1899. His measurements were all made in Wyoming, while those of the Office embraced fifteen States and Territories. The first shows the variation from year to year in the quantity of water used to grow the same kinds of crops on the same fields; the second will show the influence of soil, climate, and products in widely separated localities.

The tables and diagrams showing the dates when water was used, its volume and the relations of this use to the available supply, are worthy of study both by practical irrigators and those who have to deal with either the making or administration of irrigation laws.

The results of the measurements of water at Wheatland in 1893, given on page 46, show that the eleven crops grown on plowed land did not require irrigation before June, and the use of water ceased with the middle of August; while with ten of these crops the use of water ended in July. Forage crops grown on land not plowed were irrigated both earlier and later; but this extended use was not so much due to the requirements of the crops as to the fact that they were irrigated when water was most available, rather than when it was most needed. The total length of the season for cultivated crops was therefore less than eighty days, and the total use of water for all agricultural purposes less than six months. The table on page 48 gives the dates of irrigation at Laramie, Wyo., in 1898. These measurements embraced an unusually wide range of products, including twenty crops grown on plowed land and two fields of alfalfa. Notwithstanding

the variety of crops embraced, no water was used anywhere before June, and none on cultivated land after August. Alfalfa was irrigated later, but the use there ended in September. Although this record included about every crop grown in Wyoming outside of native hay, the total length of the irrigation period was less than one hundred days.

The same table gives the dates of irrigation at the Wyoming Experiment Station farm in 1896 and 1897. While these data include a less number of crops than those before referred to, they show in a more striking way the short duration of the period when water is required. In 1896 water was not needed until after the middle of June, and it was last used on August 14, making the total length of the irrigation period less than sixty days. In 1897 irrigation began June 25 and ended August 16, a total of only fifty-three days.

The entire series of measurements reported in this paper show that there is no considerable use of water in Wyoming before June, and that the irrigation season practically ends with August.

In the general average of the Laramie measurements given on page 50, nearly one-half of the water was used in June. Adding the depths of water used on all crops, gives a total of 240 inches, of which 187 inches were used in June and July.

The table of averages for Wheatland, on page 47, shows even more conclusively the brief duration of the irrigation season in Wyoming. Adding the depths of water used on all crops at this place, gives a total of 220 inches; 112 inches of this was the result of irrigation in June and 198 of that in June, July, and August.

Professor Buffum has stated on pages 51–55, his conclusions as to the significance of these facts. They may be summarized as follows:

Irrigation does not begin until the greater part of the water supply has escaped. The snows of the foothills and lower mountains, where most small streams rise, melt before the middle of June, which is about the date when active irrigation begins.

The use of water in irrigation is not continuous. On the contrary, there are six months in which, as a rule, water is not used at all. The practical use occurs between June 15 and August 15, or only two months out of the twelve.

Ignoring this, irrigation laws have followed mining practices where the use of water is continuous, and made rights for irrigation continuous; thus giving to ditch owners the same right for the portion of the year when water is not needed as they have for the period of actual use. This surplus right therefore is not based on any actual necessity.

In order to make the best use of the water, which now runs to waste before irrigation begins, it will have to be stored. A comprehensive system of reservoirs will require public aid, either from the State or

nation, and public supervision in the distribution of the stored water. If this is undertaken, the question will at once arise, Who owns the stored water? If it shall be held that the rights for the nonirrigation period now being acquired are vested and absolute, such rights will absorb the entire volume which can possibly be held in reservoirs. So far as Wyoming is concerned this is as yet a speculative question, but it is certain to become one of great practical importance.

The complications thus indicated by Professor Buffum have been obviated in the irrigated countries of Europe by making a well-defined distinction between rights for water for the irrigation and nonirrigation periods, and between the rights for water used strictly from the streams and rights for stored water. Few, if any, of the older irrigated districts follow our practice of making grants for streams either free or perpetual. On the contrary, the licenses issued are for a specified period and contain specific restrictions both as to the dates when water is to be taken and the purposes for which it is to be used. Without exception the districts in Europe where irrigation is most successful are those in which rights to water for irrigation are attached to the land and are inseparable therefrom. This prevents the complication regarding surplus of speculative rights, and yet at the same time gives to the actual user full protection.

The tables given in this paper show that the practice of basing the dimensions and capacities of canals on an assumed average duty for the entire season will not meet the requirements of irrigation practice in Wyoming, where two-thirds or more of the water is required in a period of sixty days. The experience of irrigators in that State has also shown this to be true. It has generally been found that when the entire area along a canal has been brought under cultivation the dimensions of the canal have been too small.

Respectfully,

ELWOOD MEAD,
Irrigation Expert in Charge.

Dr. A. C. TRUE, *Director.*

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INTRODUCTION.

There are some things about irrigation which are fairly well understood. We have learned how to build ditches and operate them in the distribution of water. The simpler laws of plant growth are becoming well understood, and the amount of water taken up by the plant, used in its development, and thrown off by it is being studied. Comparatively little effort has been made to determine how much water must be applied to the land by irrigation to mature the plant and to unravel the somewhat intricate relations between water, soil, climate, and a profitable crop. The knowledge lacking in irrigation and which must in some way be obtained before our water supply will be either wisely or correctly used is how much is required to secure the best results, and when and by what means it can be most economically and efficiently applied. The area of land in arid regions which can be ultimately reclaimed is limited by the water supply. Anything which will extend the use of this supply will add to the ultimate wealth and population of this region, but if, through lack of knowledge of the actual necessities of irrigation, rights to water are acquired which have no relation to these necessities, and these rights become fixed by custom into laws, the train of evils which will follow will seriously restrict the acreage brought under cultivation and add greatly to the cost thereof. The problem is a large one. It will require much repetition of experiments and long and careful study before the question can be fully solved, but the end in view promises returns more than commensurate with the cost.

The settlement of a vast territory, and the ultimate prosperity and happiness of its people, depend upon the artificial application of water to the land. Already the population has increased to such an extent that all the public domain in the humid States and practically all that in the arid regions which can easily be brought under irrigation has been absorbed, so that there is no longer opportunity for the sons of farmers to cultivate free land unless it be at great expense for reclamation. Already the time has arrived when many irrigated districts have so far developed that scarcity of water is keenly felt, and the

good of the community demands that there shall be no unnecessary waste of the limited water supply. Without a knowledge of the amount of water which may be available and of the amount required for the successful production of crops, who shall say whether or not the supply is economically distributed, or whether that used is adequate or inadequate, beneficial or injurious, or to what extent the land not yet irrigated may be made productive? To elucidate such weighty and far-reaching questions as these we must by actual measurements determine how much water may be obtained, how much is applied to the land and crop, how much is lost in various ways (in order to bring into practice means of preventing such losses, so far as possible and practicable), and how much is required by different crops on different soils in different climates and different seasons. By careful, persistent, and intelligent study of these factors, along with the resulting crop production, we may finally arrive at more or less definite conclusions in regard to the possibilities and limitations in our future agricultural development.

Under the best irrigation laws now in force the water belongs to the State, and the amount which the individual may appropriate for his land is not more than he is able to prove is applied to beneficial use.[1] Such laws open the way to the greatest possible development of our natural agricultural resources. The limit of that development will be known only when we know the amount of the supply and are informed in regard to what constitutes beneficial use.

The fundamental principles of the application of water to crops have been the last to receive attention. Although irrigation is almost as old as agriculture, the average irrigator readily acknowledges his ignorance of the amount of water necessary to produce a maximum crop, and his idea of the amount of water actually applied to his land year after year is about as vague and indefinite as his knowledge of the distance to the nearest star. At the same time intelligent users of water are fast waking up to the fact that this kind of information is of vast importance. Without a knowledge of the amount of water required by the land and crop no just and equitable distribution of water among appropriators can be made. Without it there is constant danger of litigation over the right to use water. Without it the determination of the man with the prior right to get his share, or all the law has given him, results in his injuring his crops by overirrigation, while his neighbor who has appropriated at a later date sees his crop destroyed by drought. Without it courts have decreed enough water

[1] This is in accord with the rulings of the Wyoming State board of control, and has hitherto governed the division of streams among appropriators. Since the paper was written this doctrine has been set aside by a district court decision, which holds that water rights are personal property and that parties can appropriate more than they need and sell the surplus.

to one man to cover his land over 500 feet deep and to another less than enough to cover it 1 foot deep.[1]

In the arid regions values attach to the water rather than to the land. Water is scarce, while land is comparatively abundant. There is approximately ten times as much land as the water supply under present usage will irrigate. The increase in value of land as soon as it is reclaimed and is insured a permanent water supply is enormous. Professor Carpenter, writing for Colorado, states that "a doubling of the duty would increase the public wealth of the State from this source alone by $20,000,000." Undoubtedly the efficiency of our water supply can be improved to a great extent when the relation of water to the soil and crop becomes properly understood—when the land has been cultivated and irrigated a number of years, and a better agricultural practice becomes general.

A knowledge of the amount of water necessary to reclaim land and produce profitable crops of the kinds which succeed under existing conditions of soil and climate is clearly a matter of first importance to the appropriator, that he may obtain enough for that purpose; to the State land boards and to the courts, that just and equitable settlement may be made of all questions relative to the use of water; and to the Commonwealth, that the greatest amount of land may become profitable and support a maximum population. Without such information legislators have adopted and reenacted land laws from other places which do not fit the conditions under irrigation at all, and too often the irrigation laws which have been put in force have been unjust and inadequate. A vast system of agriculture under irrigation has grown up in arid America, upon which thousands of families are dependent for a livelihood, and the irrigation codes have been framed for their benefit and protection, with only a limited knowledge of the water supply and the duty of water. Clearly, those laws have been most efficient and just which in some way recognize water duty, as in Wyoming and Nebraska, where they provide that the water attaches to the land irrigated by it, and the amount of appropriations are limited to the volume actually applied to beneficial use. The framers of the Wyoming irrigation laws, with great wisdom, foresaw the value of such recognition, and are to be congratulated upon establishing a code under which very little litigation has sprung up. Much trouble has been experienced in the States where companies, under the name of "common carriers," or individuals, have been given control of large amounts of water, to be used by them as an article of trade to be sold to this or that farmer who will pay most for it. When water has been diverted under individual ownership and becomes a source of speculation, and court decrees have given water in excess of the natural supply, or have provided one man with more than he can use and another with not enough

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[1] U. S. Dept. Agr., Office of Experiment Stations Bul. 58.

to carry on profitable farming, what wonder that litigation has caused expenditures of millions of dollars, or that unhappy feuds between unhappy farmers have sprung up and the irrigating shovel has become a weapon of offense and defense?

The investigations which have been carried out demonstrate that duty in any locality varies between somewhat wide limits, so that distinctions can not be too closely drawn. The limit of an appropriation should be no less than the maximum amount needed in ordinary practice. One cubic foot per second for 70 acres, as given in Wyoming, has proved sufficient under ordinary conditions, even for newly irrigated land and for native hay, which require more water than old land or other crops. More measurements of the amounts actually used on farms are needed before a close estimate can be made of what may be accomplished with the available supply.

The larger part of the material used in the preparation of this report has not heretofore been published, and has been obtained through water measurements and investigations by the Wyoming Experiment Station in cooperation with the Office of Experiment Stations of the United States Department of Agriculture. To this have been added some measurements made by the Territorial engineer of Wyoming, at Wheatland, Wyo., where the station afterwards made a series of determinations of the duty of water. It has been thought best to avoid using compilations from other sources.

APPLICATION OF WATER TO CROPS.

Every agriculturist realizes that more or less water is necessary to the growth of plants, that the larger part of the substance in the growing plant is water, and that his crops promptly dry up and die when the supply of water in the soil is exhausted. We know that water is taken up from the soil by roots, that it aids in the assimilation of food by the plant, and is lost into the air by transpiration. The nature of these processes in the plant is not related to this discussion, but the amount of water so used is of first importance.

QUANTITY OF WATER REQUIRED BY CROPS.

Some investigations of the amount of water actually needed by the plant have been made. While they are not wholly applicable to plants raised in an arid climate, they are of interest. Professor King, of the Wisconsin Experiment Station, found that the average amount of water required to produce one pound of dry matter was, in round numbers, 393 pounds with barley, 506 pounds with oats, 453 pounds with clover, 310 pounds with corn, 477 pounds with field peas, and 423 pounds with potatoes.[1] With the yields he obtained this amounts to a depth of 1.5

[1] Wisconsin Sta. Rpt. 1894, p. 248.

feet used by the crop of barley, nearly 1.6 feet by the oats, a little over 1.6 feet by the clover, and over 2 feet by corn, peas, and potatoes. According to the plan of these experiments, no account was taken of the loss of water by evaporation from the soil. These amounts are the total quantities of water received by the soil in which the crop grew and used by the plant, evaporated from the soil surface or lost by drainage, there being no other source of loss. The application of water to the plants approached the manner of supplying water in the arid region. When too much water fell as rain, it was kept away from the crops by shelter, and when the plants needed water it was supplied artificially. In every case there was increased crop when water was artificially applied, a strong argument in favor of irrigation for the humid region. In experiments of the Wyoming Station the same facts were not taken account of as in those recorded by King, but it is of interest to note the amount of water supplied to crops by irrigation and rainfall during the growing season.

Barley, which produced profitable crops, received at different times and places in our experiments from 12.8 to 37 inches of water; oats received from 20.6 to 48.8 inches of water; corn received 14.8 inches of water. This is merely a statement of the depth of water applied to the crops, and takes no account of the water lost by waste from the surface or by seepage below. Leaving out of account the unknown variations in soils and climatic conditions, it would not appear from these figures that excessive amounts of water were used in irrigation.

The following table shows the quantity of water used for a given quantity of crop harvested:

Water applied and the crop produced.

Crop.	Place.	Year.	Water received by irrigation, per acre.		Depth of water over surface.	Yield per acre.	Water used per pound of crop produced.
			Cu. ft.	*Pounds.*	*Feet.*	*Pounds.*	*Pounds.*
Alfalfa, 3 crops	Wheatland	1893	113,184	7,071,000	2.60	15,752	448.9
Alfalfa, 2 crops	Laramie	1896	47,356	2,959,750	1.09	4,664	634.6
Alfalfa, first year, 1 crop	do	1898	129,388	8,086,750	2.97	2,220	3,642.7
Alfalfa, 2 crops	do	1898	113,101	7,068,813	2.60	8,668	815.5
Barley, 3 varieties	Wheatland	1893	39,744	2,484,000	.92	1,008	2,464.3
Barley, 9 varieties	Laramie	1896	52,895	3,365,937	1.21	896	3,756.7
Barley, subsoiled	do	1896	63,296	3,958,000	1.45	1,325	2,987.2
Barley, not subsoiled	do	1896	63,296	3,958,000	1.45	1,292	3,063.5
Barley	do	1897	69,345	4,334,062	1.59	1,927	2,249.1
Barley, Highland Chief	do	1898	117,711	7,356,937	2.70	1,392	5,285.2
Barley, Highland Chief, subsoiled, straw and grain.	do	1898	75,159	4,697,337	1.73	2,168	2,166.7
Barley, Highland Chief, subsoiled, grain.	do	1898	75,159	4,697,337	1.73	527	8,913.4
Barley, Highland Chief, not subsoiled, straw and grain.	do	1898	75,159	4,697,337	1.73	2,273	2,066.6
Barley, Highland Chief, not subsoiled, grain.	do	1898	75,159	4,697,337	1.73	751	6,254.8
Corn, Minnesota King	Wheatland	1893	47,520	2,970,000	1.09	2,414	1,230.3
Flax	Laramie	1897	69,345	4,334,062	1.59	2,104	2,059.9
Flax, Belgian	Wheatland	1893	95,040	5,940,000	2.18	504	11,785.7
Flax, White Russian	do	1893	95,040	5,940,000	2.18	480	12,375.0
Oats, 3 varieties, average	Laramie	1896	53,981	3,373,812	1.24	1,555	2,169.7
Oats	do	1897	69,345	4,334,062	1.59	1,162	3,729.8
Oats, Bonanza	do	1898	82,647	5,165,237	1.90	2,465	2,095.4

Water applied and the crop produced—Continued.

Crop.	Place.	Year.	Water received by irrigation, per acre.		Depth of water over surface.	Yield per acre.	Water used per pound of crop produced.
			Cu. ft.	*Pounds.*	*Feet.*	*Pounds.*	*Pounds.*
Oats, Early Archangel	Wheatland	1893	68,256	4,256,000	1.57	1,024	4,156.3
Oats, Giant Side	do	1893	76,896	4,806,000	1.77	1,603	2,998.1
Oats, Lincoln, cultivated	Laramie	1897	107,012	6,688,250	2.46	1,662	4,024.2
Do	do	1898	75,853	4,740,812	1.74	992	4,779.0
Oats, Lincoln, field culture	do	1897	107,012	6,688,250	2.46	1,456	4,593.6
Do	do	1898	75,853	4,740,812	1.74	530	8,944.9
Oats, Lincoln, on sod	do	1898	112,579	7,041,181	2.58	698	10,087.7
Oats, not subsoiled	do	1896	63,296	3,958,000	1.46	1,345	2,942.8
Oats on sod	do	1896	41,886	2,617,875	.96	542	4,830.0
Oats subsoiled	do	1896	63,296	3,958,000	1.46	1,520	2,603.9
Oats, Surprise	do	1898	82,647	5,165,237	1.90	2,150	2,402.4
Oats, Surprise, not subsoiled, grain.	do	1898	75,159	4,697,337	1.73	1,576	2,980.5
Oats, Surprise, not subsoiled, grain and straw.	do	1898	75,159	4,697,337	1.73	4,445	1,056.8
Oats, Surprise, subsoiled, grain.	do	1898	160,835	10,052,187	3.69	1,634	6,151.9
Oats, Surprise, subsoiled, grain and straw.	do	1898	160,835	10,052,187	3.69	5,484	1,833.0
Oats, Surprise, subsoiled, grain.	do	1898	75,159	4,697,337	1.73	1,303	3,607.8
Oats, Surprise, subsoiled, grain and straw.	do	1898	75,159	4,697,337	1.73	3,645	1,288.7
Oats and vetch for hay, cured hay.	do	1898	68,753	4,295,062	1.58	5,563	772.1
Peas, straw and grain	do	1897	74,699	4,668,687	1.71	3,232	1,444.5
Peas	do	1898	124,309	7,769,312	2.85	828	9,383.2
Potatoes, 22 varieties	Wheatland	1893	61,776	3,861,000	1.42	7,344	525.7
Potatoes	Laramie	1895	11,683	730,186	.27	9,000	81.1
Potatoes, not subsoiled, irrigated 3 times.	do	1898	49,825	3,114,062	1.14	8,759	355.5
Potatoes, not subsoiled, irrigated twice.	do	1898	12,925	807,812	.30	4,972	162.5
Potatoes, subsoiled, irrigated 3 times.	do	1898	49,825	3,114,062	1.14	8,591	362.5
Potatoes, subsoiled, irrigated twice.	do	1898	12,925	807,812	.30	5,290	152.7
Rye	do	1897	69,345	4,334,062	1.59	1,518	2,855.1
Rye, spring	Wheatland	1893	56,160	3,510,000	1.29	974	3,603.7
Rye, winter	do	1893	38,448	2,403,000	.88	739	3,251.7
Sugar beets, 4 varieties	do	1893	107,128	6,695,500	2.46	12,912	518.5
Sugar beets and ruta-bagas	Laramie	1898	69,875	4,367,187	1.60	5,622	776.8
Timothy	Wheatland	1893	102,384	6,410,000	2.35	2,212	2,897.8
Turnips and ruta-bagas	Laramie	1895	112,733	7,047,812	2.59	18,000	391.5
Wheat, 18 varieties, average	do	1896	53,981	3,373,812	1.24	1,868	1,806.1
Wheat, 5 varieties, average	do	1898	158,001	9,775,062	3.63	1,573	6,214.3
Wheat, Blount No. 16, cultivated.	do	1897	107,012	6,688,250	2.46	630	10,616.3
Do	do	1898	75,853	4,740,812	1.74	841	5,637.1
Wheat, Blount No. 16, field culture.	do	1897	107,012	6,688,250	2.46	965	6,930.8
Do	do	1898	75,853	4,740,812	1.74	930	5,097.6
Wheat, not subsoiled	do	1896	63,296	3,958,000	1.46	997	3,969.9
Wheat, on sod land	do	1896	41,886	2,617,875	.96	428	6,116.5
Wheat, Scotch of Scotch, not subsoiled, grain.	do	1898	75,159	4,697,337	1.73	833	5,639.1
Wheat, Scotch of Scotch, not subsoiled, straw and grain.	do	1898	75,159	4,697,337	1.73	2,127	2,208.4
Wheat, Scotch of Scotch, subsoiled, grain.	do	1898	75,159	4,697,337	1.73	527	8,913.4
Wheat, Scotch of Scotch, subsoiled, straw and grain.	do	1898	75,159	4,697,337	1.73	2,170	2,164.7
Wheat, subsoiled	do	1896	63,296	3,958,000	1.46	943	4,197.2
Wheat, White Russian	Wheatland	1893	69,984	4,374,000	1.61	1,962	2,229.4
Wheat, winter, Fultz	do	1893	41,040	2,565,000	.94	486	5,277.8

The weight of crop harvested is subject to much variation. In some instances it will be noted that only the number of pounds of grain produced is given, while in others the grain and straw were weighed but no account was taken of the stubble which was left in the field. The amount of crop here given does not represent the dry matter, so the results in this table are in no way comparable with those given by

King, cited above. The amount of water per pound of crop varies with all the conditions affecting the duty of water, and with all the conditions affecting the yield of crop as well. It simply shows the amount of water used and the yield obtained as the crops are usually taken from the field by the farmer. With large yields from sod land, which requires a large amount of water, the number of pounds of water applied for each pound of grain harvested is very large, being about ten thousand to one in some instances; while with potatoes, which produce large crops with little irrigation, the amount of water is as little as 81.1 pounds for each pound of crop. The average of four measurements of alfalfa shows 1,385.2 pounds of water for each pound of cured hay; eight measurements of barley show 3,659.8 pounds of water for each pound of threshed grain; eighteen measurements of oats give 4,107.4 pounds of water for each pound of grain; six measurements of potatoes give 273.3 pounds of water for each pound of marketable potatoes; and fourteen measurements of wheat average 4,854.3 pounds of water for each pound of grain.

It will be observed that there is a limit to the volume of water which can be used to advantage, beyond which it is an injury to both land and crop. With alfalfa the largest yield was obtained with the least water per pound produced, and the same is true in several cases with the grains and potatoes. However, it will be found in the results recorded in the table that in general the greatest depth of water applied to the crop in irrigation nearly corresponds to the maximum yield, except in the case of grains on sod land, or potatoes, which received little irrigation.

It will thus be seen that we are unacquainted as yet with the amount of water necessary to produce the best results under any known conditions. With too little water, failure of the crop is certain, and too much water is often injurious. So far, we have been able to obtain only a general idea of the amount of water necessary to carry on successful agricultural operations and produce crops which give larger average yields than those raised under rainfall. Undoubtedly, applying water to the plant when it needs water and not forcing it to exist in the presence of water in excess of that required is the only scientific way of producing crops.

WHEN TO IRRIGATE.

The question of when to irrigate is so closely related to the water supply and its consumption that it merits careful consideration. The time to irrigate depends largely on the crop, the weather conditions, and the soil. Over a large part of Wyoming, where meadows are irrigated for the production of hay, it is the common practice to turn the water on the land just as early in the spring as it can be run

through the ditches. Ordinarily the water is placed on the meadows about the middle of April and runs continuously until about the middle of July, being turned off only long enough before mowing to allow the land to dry out so the water will not interfere with the work of haymaking. This time varies in different places from one day to two weeks before mowing begins. One farmer has stated that he turns the water off his meadows the day he begins to cut the grass, and depends upon the land drying rapidly enough so the moisture will not interfere with curing the hay; and another explained that he had obtained a mowing machine which would cut right along under 6 inches of water.

Various reasons are given for turning the water on the meadows as early as possible. A ranchman, who raises excellent crops of hay on the Laramie plains, states that the water draws the frost out of the soil, softening the land so the grass can make an early start and produce larger growth than where naturally held back by the cold weather. Another ranchman near Laramie says: "Where the soil is covered with alkali (and practically all the land here is alkali land) the white incrustations of salts interfere with the growth of grass and keep the land cold by reflecting the sun's rays. If the water can be run over the land enough to wash off the alkali, or dissolve it and carry it into the soil, the grass thickens up and makes a good crop." Whatever the reason, it is evident that the ranchmen of Wyoming, as a rule, believe in irrigating native hay land as early and as long as possible, and all use the most water when the largest amounts can be obtained from our streams, which is during May and June.

The time to irrigate cultivated crops can not be definitely stated. Absolutely no working rule has been discovered. Up to the present time farmers have generally applied water through judgment born of long experience, rather than through an intelligent conception of the needs of the plant. Often the one who irrigates can not explain clearly how he knows his crop is in need of water. To the uninitiated the crop may be apparently thriving and the need of water seemingly remote, when the farmer turns on a head of water and does not rest day or night till all his land has been watered. Evidence of his correct judgment is forthcoming in the large yields which fill his granaries and root cellars. Some say that plants do not need irrigating until they show signs of wilting, but for most plants this would be waiting too long. The crop would never fully recover its strength and vigor. This rule may be applied to corn, however, which is ordinarily said not to be suffering so long as the wilted leaves straighten out at night. Some farmers will inform you that they discover when water is needed by the color of the plant; but this is not an altogether safe guide, for color is influenced by so many other conditions that it can not be relied upon as an index to the need of water. More intel-

ligent farmers will probably explain that they have examined their soil and know from experience that when it reaches a certain condition of dryness their crops will soon suffer unless water is supplied. Dr. Hilgard, of the California Experiment Station, states that this questioning of the soil is the only accurate way to tell when irrigating should be done. The percentage of moisture in the soil in which plants of different kinds flourish best is not known, and much experimenting will be necessary before definite rules based on this factor can be formulated. That there are periods in the life of the crop when irrigation will be especially effective can not be doubted, and it is equally true that irrigating at the wrong time may do more harm than good. The opinions of neighboring farmers in regard to the proper time may vary widely, and the one who makes the closer guess reaps the larger crop. To illustrate—in 1898 a question arose in regard to when potatoes should be given the first irrigation. The opinion of old irrigators differed so widely that it was decided to put the matter to the test. A part of the potato field was given the first irrigation July 7, while a part was left until July 28 for the first watering, at which time the potatoes irrigated on July 7 were given their second irrigation, and all were irrigated again on August 4. The potatoes were planted in rows running across two plats, one of which was plowed in the ordinary way. The other plat was treated the same, but had been subsoiled in the spring of 1896 to a depth of 16 or 18 inches. The potatoes irrigated twice received 3.6 inches of water, while those irrigated three times received 13.8 inches. The yields of marketable potatoes per acre are given in the following table:

Yield of potatoes with two and three irrigations.

Irrigations.	Land plowed.	Land plowed and subsoiled.	Average yield.
	Pounds.	*Pounds.*	*Pounds.*
Irrigated twice	4,972	5,290	5,131
Irrigated three times	8,759	8,591	8,675
Increase	3,787	3,301	3,544

This table shows an increased yield due to the additional irrigation of over 76 per cent on land treated in the usual way, and of nearly 62.4 per cent on subsoiled land, the average increase being over 69 per cent. This shows that with potatoes, at least, irrigation should not be put off until the crop begins to burn, as is often done with grain. Many withhold water from their potatoes until the young tubers are set, in order not to stimulate the vines into forming more tubers than will grow to good marketable size, while others try to irrigate before or at the time of setting the tubers. No experiments are at hand to show which of these two methods is preferable,

There is much difference in the number of irrigations given the same kind of crop in different places. Reference to the tables and charts (pp. 46 ff.) giving the distribution of irrigation water through the season shows that five or six irrigations are not uncommon at Wheatland, while rarely more than three are given at Laramie. Some soils absorb less water and retain it less tenaciously than others. Because a crop in one place needs irrigating is no reason a like crop in another location needs water at the same time.

FALL AND WINTER IRRIGATION.

The soil itself may be used as a storage reservoir. The possibility of storing water in the soil is becoming better understood and the practice is rapidly becoming more general. In parts of Kansas it has been found possible to store enough water in the soil by winter irrigation to mature the summer's crops. There are large ranches in Wyoming with a limited supply of water on which the irrigation water is systematically spread over the hay land in the winter to supply moisture to the coming crop. Such practice enables the owner to double the amount of meadow from which he can put up hay, as the land supplied with moisture in the winter is not irrigated during the summer months and the summer supply is used on separate areas.

The value of conserving the moisture on fruit lands by mulches through the winter has long been understood and is widely practiced, and the value of winter irrigation for orchards is no longer questioned. In the arid region the winters are long and dry, there is no continuous mulch of snow, and the orchardist who can not irrigate late in the fall or occasionally through the winter is unfortunate.

The value of irrigating alfalfa in the fall has been tested by the Wyoming Experiment Station. Alfalfa irrigated late in the season, October 2 and 3, 1895, did not winterkill as badly as that not irrigated. The quantity applied can not be stated accurately, but as nearly as can be estimated enough was used to cover the land 6 inches deep. The plants which were fall irrigated started earlier in the spring and made better growth, at one time being 4 to 5 inches higher than those not so irrigated, and the dividing line marked by the water could be traced up to the time of the first cutting in 1896. In spite of the fact that evaporation was sufficient to remove nearly or quite all of this water during the winter months, its influence was felt far into the next growing season.

On land which is used for the production of cultivated crops, where the surface soil can be stirred frequently to prevent the loss of water by evaporation, winter irrigation is far more effective than on grass land. In parts of California, water supplied the land during the winter or wet season is often sufficient to mature crops, though they may not receive any water between planting and harvesting. In such places

complete and continuous cultivation is practiced to prevent the soil from losing its store of moisture through evaporation. Where water is stored in this way for the coming crop it is necessary to conserve the moisture by continually stirring the surface to form a natural mulch which will prevent evaporation.

WATER MEASUREMENTS IN WYOMING.

CONDITIONS UNDER WHICH THE MEASUREMENTS WERE MADE.

Historical and general.—A brief account of the conditions under which the water measurements reported in the following pages were made is thought advisable, as it will help the reader to a better understanding of them. Without some information of the locality in which measurements are made, the general conditions of the soil and climate, and the methods and instruments used, a clear idea could not be obtained of the manner in which the final results were reached.[1]

Measurements of the water used on the station farm have been made at Laramie since the spring of 1891, and a series of measurements were made at the substation at Wheatland in 1891 and 1893. Some measurements to determine the duty of water were made at Wheatland in 1889, under the direction of the Territorial engineer, Elwood Mead, and as they are closely related to the subsequent measurements made by the station at that place the results are used in this report.[2]

The irrigation experiments at the station have been carefully made. The water has been economically used; the irrigator has always prevented the water from going to waste, so far as possible, and confined the measurement to the special plat under investigation, in order to determine duties for each crop separately. It was thought that a series of measurements of the water actually used by farmers in their ordinary practice would be of value for comparison. In fact, it was believed that the making of such measurements was the only way to find out how the water supply is actually being used, and such information is necessary before we can point out where change in present irrigation practice is feasible or desirable. To gather this kind of information, a measuring weir and register were placed in 1898 on a farm situated on the open plains, 16 miles from Laramie, under the Pioneer Canal. The soil is a loose gravel extending to a depth of about 10 feet, and on account of the natural drainage requires large

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[1] It has been the privilege of the writer to plan and carry out the irrigation investigations at the Wyoming Experiment Station since it was established in 1891. The farm was then platted and ditches so constructed that all the water used in irrigating could be accurately measured.

[2] The duties determined at Wheatland in 1891 and at Laramie in 1891 and 1892 were reported in Bulletin 8 of the Wyoming Experiment Station. These results are also reported in this bulletin, but with the above exceptions none of the measurements used in the preparation of this report have been heretofore published.

amounts of water. The owner of the farm used the water exactly as he would otherwise have done, and we secured trustworthy measurements of the water so used.

The experiment farm is situated 2 miles west of Laramie, under the Pioneer Canal. The land slopes toward the east, with a grade of from 3 inches to 1 foot to 100 feet, but the soil does not wash badly even where the slope is greatest. The soil is a sandy loam from 15 or 18 inches to over 5 feet deep, and the greater part of the farm is underlaid with gypsum and carbonate of line, and with sandstone. The soil is sticky when wet and of such consistency that it is difficult to make a plow scour in it at any time unless it is very dry. The soil absorbs water readily, and seems to retain the moisure better than most open and loose soils in this region. The altitude of the station farm is about 7,200 feet; it is situated on the open plains without protection of any kind, and the drying winds of winter and spring leave the soil with little moisture unless it is irrigated.

The growing season is comparatively short; usually frost is out of the ground so plowing can be done by April 10. Spring frosts of greater or less severity may be expected up to June 1, and a light early frost about August 20, though killing frosts may hold off until September 10 or 20. On account of the short season, only those crops can be successfully raised which can stand a few degrees of frost after the seed is sown in the spring.

The farm upon which measurements were made at Wheatland is at an altitude of about 4,700 feet; the soil is much like that at Laramie, though it is deeper and probably contains smaller amounts of gypsum and alkali salts. The land has a gentle slope, which makes it irrigate well. It is on the open plains with no protection from the winds, but the season is long and killing frosts often hold off in the fall until as late as the middle of October.

The methods of applying water used have been flooding and furrow irrigation. As a rule grains and grasses are irrigated by flooding, and potatoes and other root and garden crops by the furrow method. In some of our experiments grains were raised in rows, planted twice as far apart as the ordinary drill row. These grains have been irrigated in small furrows between the rows and otherwise cultivated as hoed crops. An expert irrigator will handle a large head of water with either of these methods, without allowing appreciable waste.

A second weir was placed on the lowest point of the farm at Laramie to measure the waste water, but so little escaped that the flow over a 1-foot weir was too small to be accurately determined, and such measurements were discontinued.

Precipitation and evaporation.—The precipitation and evaporation of the region in which the measurements were made as observed at Laramie since 1891 are shown in the following table:

Precipitation and evaporation, Laramie, Wyo.

Month.	1891.		1892.		1893.		1894.	
	Rainfall.	Evaporation.	Rainfall.	Evaporation.	Rainfall.	Evaporation.	Rainfall.	Evaporation.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
January	0.70	....	0.01	....	Trace.	....	0.03	....
February	.375	....	.36	....	0.11	....	.10	....
March	1.50	....	.52	....	.29	(*a*)	.29	....
April	.25	....	.19	(*b*)	.32	*c* 0.562	1.51	*d* 0.906
May	2.92	....	1.16	*e* 1.59	.33	4.801	.42	6.06
June	.91	....	3.97	8.23	.54	7.884	.64	7.492
July	1.20	*f* 4.424	2.22	9.19	.34	9.352	1.41	6.69
August	1.76	8.59	.14	8.27	1.08	6.586	1.26	6.276
September	1.80	5.04	Trace.	6.10	.39	6.016	1.60	6.436
October	.30	3.72	3.96	*g* 1.50	.28	2.886	.09	3.306
November	1.095	*h* .926	Trace.	....	.06	....	.05	....
December	1.11	....	.20	....	.10	....	.23	....
Total	13.92	22.70	12.73	34.88	3.84	38.087	7.63	37.166
Total precipitation for May, June, July, and August	6.79	....	7.49	....	2.29	....	3.73	....

Month.	1895.		1896.		1897.		1898.	
	Rainfall.	Evaporation.	Rainfall.	Evaporation.	Rainfall.	Evaporation.	Rainfall.	Evaporation.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
January	0.08	....	0.44	....	0.39	....	0.05	....
February	.14	....	.17	....	.16	....	.01	....
March	.43	....	.59	....	3.97	....	.40	....
April	.87	*i* 2.55	3.53	....	.55	*c* 1.80	1.26	*j* 3.44
May	2.09	7.334	.48	....	1.85	7.43	1.88	4.60
June	2.12	6.236	1.72	7.79	.72	7.73	.90	*k* 10.33
July	2.71	7.294	1.66	8.34	1.29	7.00	.65	8.37
August	1.17	6.066	.89	6.09	1.11	7.33	1.16	6.93
September	.18	4.944	1.16	4.84	.32	4.84	Trace.	5.68
October	.74	2.616	.18	*l* 2.00	.55	*m* 4.38	.48	*n* 2.05
November	.32	....	.09	....	.33	....	.61	....
December	.33	....	.00	....	.75	....	.23	....
Total	11.18	37.02	10.91	29.06	11.99	40.51	7.63	41.40
Total precipitation for May, June, July, and August	8.09	....	4.75	....	4.97	....	4.59	....

a From October 1, 1892, to October 1, 1893, evaporation was, apparently, 46.305.
b Evaporation between November 11, 1891, and May 24, 1892, was 9.69 inches. Liable to considerable error.
c 24th to 30th.
d 26th to 30th.
e 24th to 31st.
f 22d to 31st.
g 1st to 10th.
h 1st to 11th.
i 17th to 30th.
j 15th to 30th.
k An exceptionally dry and windy month.
l 1st to 22d.
m 1st to 26th.
n 1st to 15th.

Although the rainfall is small (averaging 9.95 inches for the eight years) its distribution through the year is most favorable for crops. The month of heaviest rainfall is usually May or June, and enough is generally obtained early in the season to insure germination, so the crop can begin its growth without being irrigated. There are serious objections to irrigating after the seed has been sown, to bring the

plants up, as the crop rarely fully recovers. Where the soil is too dry to insure proper germination it should be irrigated before plowing or at least before planting. In the table the annual precipitation and the amount for four months—May, June, July, and August, the arbitrary irrigating season here adopted—are given; a mean of 5.33 inches has fallen during these months, which is very nearly 54 per cent of the annual precipitation. The average here given for eight years is probably below the normal for Laramie, as that of 1893 was unusually small, not only at Laramie, but over the whole eastern part of the State. It may be remarked here that water failed in the Pioneer Canal early in that season, and the rainfall, being so small, was insufficient to carry the plants through, so general failure of crops on the experiment farm resulted in 1893. As already stated, the growing season at the high altitude of Laramie is comparatively short, and any cause which delays the time of maturity, even a few days, may be fatal. A heavy rain when the crop first requires water may preclude the necessity of irrigating for one or two weeks, and its effect upon the amount of irrigation water needed to mature the crop is apparent. Without considering the rainfall in each case, a clear understanding could not be obtained of the duties of water reported, so great care has been taken to accurately report precipitation in connection with the tables of duties.

The evaporation is heavy over the larger part of the arid region, and while we have not been able to measure the evaporation accurately for the entire year, it has been carefully observed for the season when the water was not frozen. The measurements of evaporation were made from a galvanized iron tank of 1 cubic meter capacity set into the ground even with the surface. The water was accurately measured each day by means of a hook gauge, and the tank was filled from time to time to keep the water near the top so that evaporation would not be influenced by reflections of heat from the sides of the tank.

Observations from October 1, 1892, to October 1, 1893, indicated that the total loss from water surface during the warm months, together with that from snow and ice in the tank during the cold months, was over 46 inches, and other observations since that time indicate that the annual evaporation will range from this amount to as much as 60 inches. In single months which are dry and windy during the growing season, evaporation of from 7 to 10 inches is not uncommon. For the year evaporation from water surface amounts to four or five times the amount of rainfall, and in single months it may be twenty-five or thirty times the amount of water supplied by precipitation. The loss from streams, ditches, and reservoirs in the arid region from this cause is enormous. A loss of 4 feet from a reservoir or ditch covering 1 square mile of surface means the disappearance of enough water in a

year to irrigate over a thousand acres.[1] Many soils retain moisture for a longer period of time than it would take the same amount of water to evaporate from water surface. Their ability to retain their moisture depends upon chemical and physical characteristics. As Hilgard has pointed out, soils which contain large amounts of alkali salts always appear more moist than surrounding soils upon which salts have not accumulated. Unfortunately few observations on evaporation from soils, which will apply to arid conditions, are available.

UNITS OF MEASUREMENT.

That the measurements here reported may be fully understood by those who are unacquainted with irrigation, the following brief definitions of terms are given:

In measurements to determine the supply in streams and the amount used in irrigation the second-foot is universally adopted. The second-foot is the flow of 1 cubic foot of water for each second of time and is a most convenient unit, easily reduced to any of the terms in which quantity of water is expressed. It amounts to approximately 62.5 pounds or 7.8 gallons each second. One cubic foot per second continuous flow for 12.1 hours equals 1 acre-foot, i. e., enough to cover 1 acre 1 foot deep, or 43,560 cubic feet.

Over perhaps the largest part of the irrigated region of the West the unit of measurement into laterals from canals is the "miner's inch." This unit is supposed to represent the amount of water flowing through an aperture 1 inch square under conditions defined by law. Usually the opening is so placed that there is a certain depth of water above the opening, known as the pressure head. In some places the water is measured to users with no pressure head; in other places a pressure of 4 inches is given, and in still others a pressure of 6 inches. In point of fact, there is little uniformity in the use of the miner's inch, and there is a corresponding variation in its value. There are two forms of the miner's inch—the California inch and the Colorado inch—which differ in value. Fifty California miner's inches is equal to 1 second-foot, while 38.4 Colorado inches is equal to 1 second-foot. In actual practice the methods of measuring out the miner's inch probably cause variation in the amount of water greater than the difference in size of the Colorado and California standards. Without a complicated device it is difficult, if not impossible, to control the

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[1] An article was published in the Monthly Weather Review for September, 1888, giving a large number of determinations of evaporation through the year in various parts of the United States. In general, the evaporation was less than the rainfall in the humid States. The smallest evaporation recorded was 18.1 and 19.1 inches on the North Pacific coast. The maximum amounts were 101.2 inches at Fort Grant; 100.6 inches at Keeler; and 95.7 inches at Yuma, on the Southern plateau. At Fort Custer, Mont., it was 52 inches; at Cheyenne, 76.5; and at Denver, 69 inches.

depth of water above the opening, and small variations in this pressure head produce appreciable differences in the amount flowing through the opening. In California the duty of water is often expressed in the number of acres for which 1 inch continuous flow is sufficient, as statements are often met that 1 inch is sufficient for 5, 8, 10, or 12 acres.

HOW THE MEASUREMENTS WERE MADE.

Measurements of water are of little or no value unless they are accurately made. There are two methods of making trustworthy measurements in common use. That usually adopted in measuring streams is to obtain the velocity of the current in feet per second by means of an instrument designed for the purpose, and multiply the velocity by the area of the cross section of the stream in square feet, which gives the number of cubic feet flowing by in each second of time. An appropriator in Wyoming is required to place a box in his ditch in which the cross section of the stream can be easily determined and the velocity measured at any time. In order to obtain a continuous record we must furnish an instrument which will record the time of flow and fluctuations in depth, in which case it is necessary to know from actual determination the average velocity of the stream for each depth, if there is much rise and fall. Where there is much sediment in the water, or where the conditions are such that a measuring weir can not be located, the amount of water used can be determined with such a box and recording instrument.

All the measurements made by the Wyoming station and reported in this bulletin were made over a weir, which does away with the necessity of making determinations of average velocities of the stream. The Cippoletti trapezoidal weir, in which the sides are inclined at one-fourth horizontal to one vertical, was adopted. In order to fulfill the conditions necessary for accurate measurement, large boxes 6 feet square and 3 feet deep were constructed (Pl. I, fig. 1). The water from the lateral runs into the rear end of the box and out over the weir, which is placed in the forward end. A notch for the weir is made in the middle of a wide board which fits into the end of the box between cleats, like a gate, so it can easily be removed and a board with different length of weir used, if needed. This is found convenient, as the depth of the water flowing over the weir should not be less than 3 inches nor more than one-third the length of the weir. Then, if a large head of water is needed in the irrigation, a long weir may be used, and if only a small head is required a shorter weir is substituted, which arrangement may often overcome sources of error in the measurements. To give sharp edges to the sides and crest of weir used, strips of galvanized iron were screwed onto the side from which the water came, leaving the crest or base of the weir 12, 18, or 24 inches long.

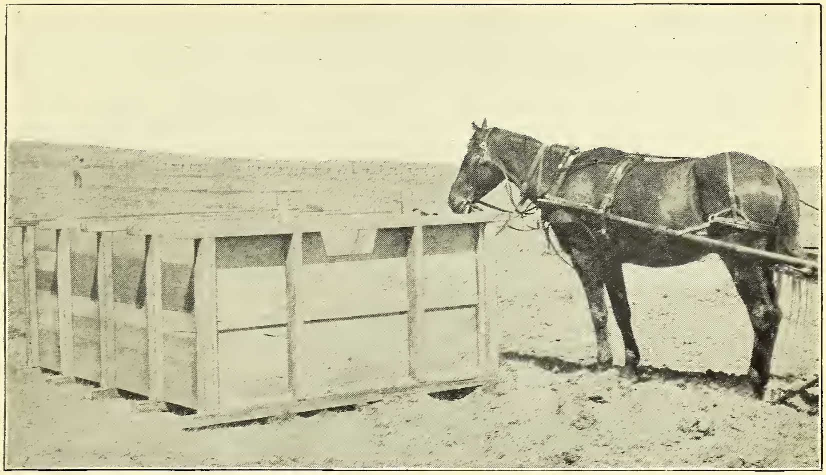


FIG. 1.—A WEIR BOX, SHOWING A NOTCH FOR A 1-FOOT WEIR BEFORE BEING SET IN LATERAL, WYOMING EXPERIMENT STATION.

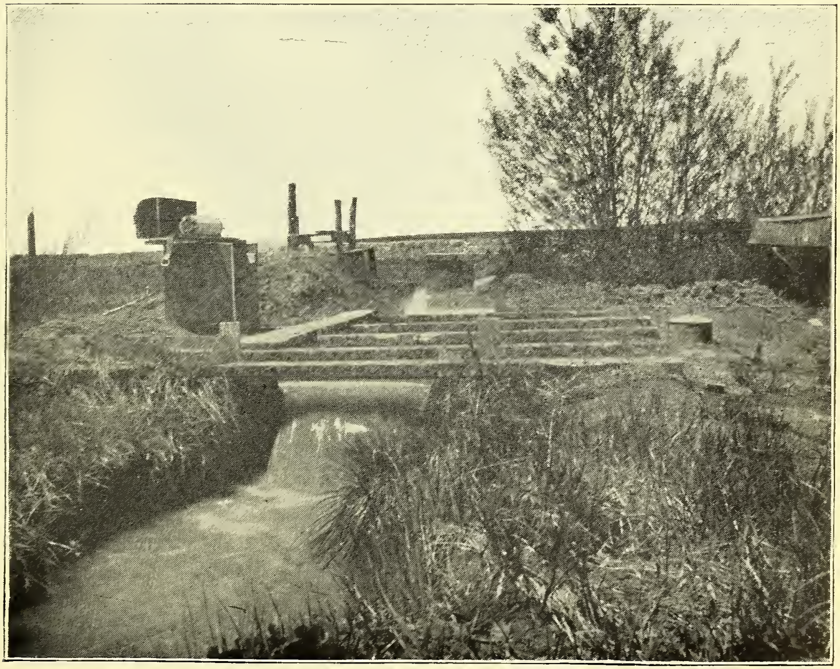


FIG. 2.—MEAD WATER REGISTER AND WEIR IN USE AT THE WYOMING EXPERIMENT STATION.

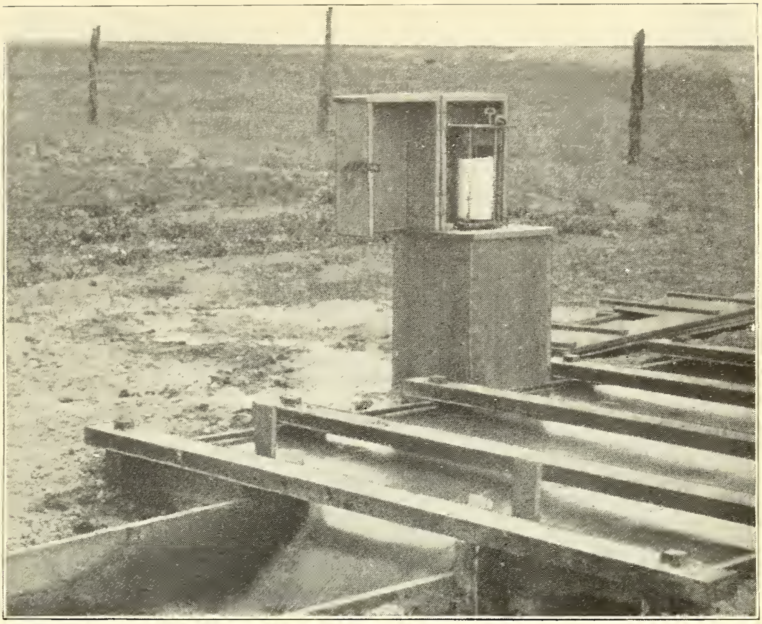


FIG. 1.—WYOMING NILOMETER AND WEIR IN USE AT THE WYOMING EXPERIMENT STATION. BEYOND THE REGISTER THE CHARACTER OF THE UNIRRIGATED PLAINS IS SHOWN.

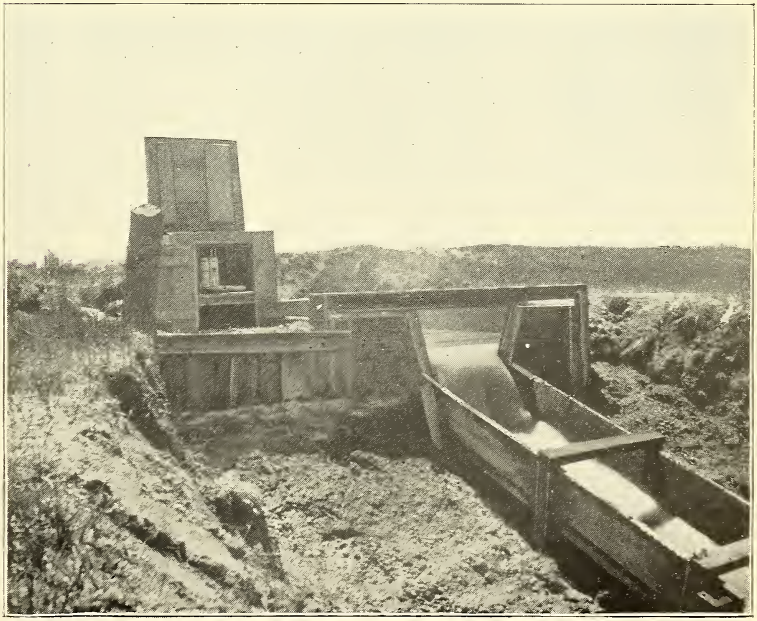


FIG. 2.—WYOMING NILOMETER AND WEIR IN USE ON A FARM NEAR LARAMIE, WYO.

This form of weir has two important advantages over the rectangular weir in which the sides are vertical. In weirs of different lengths the discharges are proportional to the lengths, i. e., the amount of water flowing over a 2-foot weir will be twice that flowing over a 1-foot weir, with but a small error, the depth remaining the same, and the slope of the sides is such that no coefficient for end contractions need be used in the formula, which makes the computations much easier. The formula for computing the quantity of water running over the trapezoidal weir is $D=3.3\frac{6}{8}\ L\ H^{\frac{3}{2}}$, in which D equals the discharge in cubic feet per second, L is the length of the weir in feet, and H equals the depth of the water flowing over the weir in feet.

A water register is used to give a record of the time the water flows over the weir and its depth. The water register consists of a clock to keep the time, a cylinder or disk upon which the paper which is to receive the record is placed, and a float in the water, either attached to the cylinder or a marking pen to record all variations in the depth of the water. The clockwork may either turn the cylinder and the pen be moved lengthwise of the cylinder as the float rises and falls, or the pen may be propelled by the clockwork and the cylinder revolved forward or backward by the changes in height of the float. It would seem that so simple an instrument could be manufactured at small cost, but the accuracy required in these instruments renders any so-called cheap register yet devised of little value. We have used several different patterns of water registers. The first instrument used by the Wyoming Station was the Wyoming nilometer, designed by Elwood Mead (Pl. II). This instrument, which has given very satisfactory results, consists of a vertical cylinder turned by a clockwork at the top and a pen moved up and down by a float attached to a line running over a pulley. A new register, also designed by Elwood Mead, for the irrigation investigations of the Office of Experiment Stations of the U. S. Department of Agriculture, is now used in making water measurements on the Wyoming Experiment Station farm (Pl. I, fig. 2). In this the cylinder is placed horizontally, and is turned by a line passing around one end and attached to the float, while the recording pen is caused to travel along the cylinder by clockwork. For a number of years we used a cheap register designed by D. A. Carpenter, in which the record is made on a dial turned by the clock. The chief objection to this instrument is the amount of work required to compute the records. A very good instrument is made in Paris, France. The pen describes an arc lengthwise of a cylinder, which is turned by the clock. The records on the register sheets which accompany this instrument are based on the metric system.

In using any register it is important to see that the clock is always in order and keeping good time, and the base line on the record, which is the line corresponding to the height of crest of the weir, must be

carefully located on each sheet. The float may change in buoyancy or the line from the float to the cylinder or pen may stretch or slip. With an 18-inch weir an error of one twenty-fifth of an inch in recording the depth of the water may cause an appreciable error in the computed amount. Accurately determining the point on the record sheet which corresponds to the crest of the weir is more difficult than it at first appears. When the water is high enough in the weir box to begin running over the crest of the weir the pen will be above the true base line, because the surface tension of the water causes it to pile up in front of the weir and lift the float an appreciable amount before the water will run over the sharp weir crest. A point on a level with the crest of the weir should be located near the float which is attached to the register, and when the water reaches this point the position of the pen will indicate the true base line on the record sheet. We have found a simple device to indicate the base line at any time a most convenient and valuable addition to the registers in use, and one has been made which will be incorporated in a new water register which has been planned for the Wyoming Station. A second float, to which a vertical rod is attached, was placed in the weir box. On this rod was placed a scale with a set screw to fasten it at any height desired. When the water in the weir box reached the height of the crest of the weir the zero point on the scale attached to the rod was set to correspond with a permanent point fixed in the register box, after which the depth of the water flowing over the weir could be read at a glance at any time and checked on the record sheet.

COMPUTING THE RECORDS.

The first step in computing records is to determine the depth recorded and the length of time the water ran at each depth. Small variations of less than an inch may be averaged; but where there is any considerable change, flowing for an appreciable length of time, the flow must be computed for such different depths and times separately. On record sheets where depth has been recorded by the pen moving in a straight line up and down, the average depth for a given time is easily obtained by the use of the planimeter, which gives the area of the figure. Knowing the area and the base of the figure, its average altitude, corresponding to mean depth of the water, would equal the area divided by the base. The flow in cubic feet per second at any depth can be obtained by applying the formula given on page 25, or by the use of tables which have been computed for the purpose.

DUTY OF WATER.

DEFINITIONS AND GENERAL CONSIDERATIONS.

What is meant by the duty of water.—The duty of water is an expression of the amount used to irrigate a given area. The great value of knowing the duty of water lies in the fact that it furnishes a means of determining the ratio between the water supply and the area which that supply will bring under profitable cultivation. The duty must be known before the size of the canal which is to carry water for a certain area can be determined. If all the facts regarding the duty of water for the crops raised were known, the greatest economy could be secured both in the construction of the necessary works and the application of the proper amount of water to produce the best results.

In the work of the Wyoming Station the crop factor has always been taken into account, and unless crops were matured the measurements of the water used have not been reported as duties. In 1893, when crops at the station failed because of the dry year and the lack of water in the first part of the season, the measurements were not reported as duties because enough water was not used to accomplish the results for which irrigation was practiced. Such measurements, if reported, would be misleading, as they would in no way represent the amount of water which must be supplied the irrigator in order to enable him to do profitable farming.

Terms in which duty is expressed.—There are several ways in which the duty of water may be stated. The usual method in vogue up to the present time has been to give the number of acres which a flow of a cubic foot per second will irrigate. This depends upon the length of the irrigating season, which is a varying factor. The length of the irrigating season usually adopted in expressing duty is four months (May, June, July, and August) or one hundred and twenty-three days. Sometimes ninety-five days is used, which more nearly corresponds with the length of the growing season. This is a purely arbitrary factor and one which causes considerable confusion, as it does not at once convey a definite idea of the amount of water used. The irrigating season is not necessarily synonymous with the growing season, though it is sometimes understood as the time from the first to the last irrigation of a given crop. In case of winter irrigation, which is acknowledged to be a good practice and often necessary with orchards and where the soil is used as a storage reservoir to save the moisture, the irrigating season would cover the whole year. The necessity of adopting a given length of time for all crops makes the expression of duty in acres per second-foot inaccurate. In the opinion of the writer the better method of expressing duty is to give the total amount used

per acre for each crop. This may be expressed in acre-feet, or what is equivalent, in the depth to which the water used will cover the land; or again, in the total number of cubic feet used upon an acre of land. As the amount of water is so intimately associated with the rainfall, it seems that the total depth of water received by the land during the season, both from irrigation and rainfall, with information of the rainfall during the rest of the year, gives a more definite and satisfactory idea of what is required by each crop. In this bulletin the duties are expressed in the several ways mentioned in order that a definite idea may be obtained of the amount of water used and that these duties may be compared with those reported by other writers.

Duty of water variable.—The duty of a continuous flow of a cubic foot of water per second has been reported for different crops and different places, ranging all the way from a minimum of one-half acre in France, 1 to 18 acres in Italy,[1] and 7 acres in California,[2] to a maximum of 2,200 acres in Spain. Expressed in the depth to which the water would cover the land, this gives a minimum of less than 3 inches and a maximum of 1,400 feet in a year. In one case, where sewage was used for irrigation on sandy and gravelly soil near Paris, enough was supplied during the season to cover the land to a depth of 38.2 feet.[3]

The duty determined so far in Wyoming, calculated on the basis of one hundred and twenty-three days as the irrigating season, varies with different crops and in different years from 65 acres with native hay to 908 acres with potatoes.

The duty of water is sensitive to many modifying conditions. It varies with the character of the soil and the subsoil; with the slope and the smoothness of the land; with the amount of land; with the length of time the soil has been cultivated and irrigated; with the presence or absence of water supply from below; with the rainfall and its distribution through the year; with the altitude, temperature, wind, and other conditions affecting water movement, evaporation, and crops; with the kind of crop; with the length of the irrigating season and the diversity of crops, which enables rotation in the application of water in order to keep it constantly in use; and with the skill and economy of the irrigator.

Wherever there is waste it must be made good by drawing on the supply. Water may be lost by escaping from the surface instead of being absorbed by the soil during the time irrigation is being done, or it may be lost by seepage through a porous subsoil. After the water

[1] Flynn's Irrigation Canals, p. 293.

[2] Irrigation at Bakersville, Cal.; Water Supply and Irrigation Papers No. 17, U. S. Geological Survey.

[3] Sewage Irrigation; Water Supply and Irrigation Papers No. 3, U. S. Geological Survey.

has been applied it is continually being lost through evaporation from the surface, and where evaporation is great more water will be needed. Therefore different methods of irrigation and cultivation may make a great difference in the duty of water on the same soil and crop. In studying duty it is therefore important to have a record of all these modifying conditions.

DUTIES FIRST DETERMINED IN WYOMING.

The first measurements to determine the duty of water in Wyoming were made by the Territorial engineer, Elwood Mead, in 1889, at Wheatland. The results reported below are taken from the second annual report of the Territorial engineer.

Quantity of water used on oats and potatoes at Wheatland, Wyo., in 1889.

Rainfall and irrigation.	April.	May.	June.	July.	August.	Irrigating season.
Oats:	*Inch.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Depth of rainfall	0.50	3.45	3.37	1.99	0.75	10.06
Depth of irrigation			7.236	21.936	2.124	31.296
Irrigation and rainfall	.50	3.45	10.606	23.926	2.874	41.356
Potatoes:						
Depth of rainfall	.50	3.45	3.37	1.99	.75	10.06
Depth of irrigation				12.744		12.744
Irrigation and rainfall	.50	3.45	3.37	14.734	.75	22.804

SUMMARY.

Item.	Oats.	Potatoes.
Total amount of water used ... cubic feet	14,056,235.55	323,825.
Time employed ... days	54.5	1.5
Area of surface ... acres	123.7	7
Average discharge for period used ... cubic feet per second	3.79	2.5
Equivalent average discharge for irrigating season of four months (May, June, July, August) ... cubic feet per second	1.32	.0305
Or an equivalent duty of 1 cubic foot per second for continuous discharge ... acres	93.8	229.5

In the discussion of the above results it is stated that—

The depth of the water spread over the surface in July (nearly 2 feet) seems unnecessarily large, and to those unacquainted with the enormous evaporation which takes place during the summer months it would seem that such a volume of water would be ruinous. The results, however, sustain the judgment of the irrigator. Part of the field was damaged by hail, yet the average yield was 40 bushels per acre, and 1 measured acre in the unharmed portion gave a yield of 75 bushels.

The potatoes upon which water was measured gave a yield of 150 bushels per acre.

Measurements of water made at Laramie and at Wheatland by the Wyoming Station in 1891 and 1892 have been reported.[1] As the duties are closely related to those afterwards obtained on the same lands and

[1] Wyoming Sta. Bul. 8.

reported in the following pages they are repeated in the next table. The land on which these experiments were made was sod, broken in the spring of 1891. The sugar beets and ruta-bagas, corn, cane, peas, and beans were planted in rows and irrigated in furrows. All other crops were irrigated by flooding.

Duty of water, Wyoming Experiment Station, 1891–92.

Place.	Crops.	Yield per acre.	Rainfall for four months.[a]	Date irrigated.	Total amount of water used.	Average depth of irrigation water on land.	Duty of 1 cubic foot per second continuous flow.
			Inches.		*Cubic feet.*	*Inches.*	*Acres.*
1891.							
Laramie	Mixed		6.16		2,667,288.75	30.6	95.62
Wheatland	Oats	40 bushels.	3.50	June 20 to July 12.	9,507,073.47	17.4	167.69
1892.							
Laramie	Sugar beets; Ruta-bagas	8.6 tons; 18 tons.	[b] 6.99	June 16, 17; Aug. 16; Sept. 22	97,973.24	9.9	299.77
Do	Corn	Cut for fodder.	[b] 6.99	July 20	10,848.39	4	735.29
Do	Cane, durra		[b] 6.99	July 23	19,754.92	8.7	336.02
Do	Peas, beans	7 bushels	[b] 6.99	June 5	18,081.13	4.9	588.23
Do	Mixed		[b] 6.99		1,180,511.41	13.5	216.06

[a] Four months of growing season—May, June, July, and August.
[b] 5.13 inches fell in May and June.

DUTIES FOR DIFFERENT CROPS.

The amount of water required by different crops varies enormously. In desert regions where the rainfall does not exceed 4 or 5 inches, while evaporation would amount to more than 100 inches if there were water to evaporate, there are many kinds of plants which live and when supplied with a small amount of water produce flowers and fruit. During the greater part of the year, when no water is available, they merely suspend growth. On the other hand, there are plants which will not live unless continuously standing in water or having the larger part of their roots and stems completely covered with it. In the different varieties of the same kinds of plants there is marked difference in ability to stand drought and to produce a crop with a scanty water supply. A variety of oats which needs only ninety days to mature its grain and which throws all its force into the production of seeds rather than straw will produce a crop with a small part of the water required by a variety taking one hundred and eighty days to mature and producing long, coarse straw. The two extremes have actually been observed at Laramie. Many plants also have the power to adapt themselves to the soil and climate. Oats will grow in the Tropics or in a region marked by frosts every month of the year. Such changes in the plant may change its requirements somewhat, so that the duty for the same crop will undoubtedly vary according to variety and such conditions of adaptation as may have become established.

Although irrigation has been practiced for centuries, it is still of

first importance to know how much water is actually used on crops, when it is used, and with what results, before we can know where improvement is possible. We can not say that the duties so far obtained are the true amounts which are necessary to produce maximum crops, although where large crops result the judgment of the irrigator is sustained.

RECENT EXPERIMENTS ON THE DUTY OF WATER.

Measurements have been made at the Wyoming Experiment Station every year since those reported in 1891 and 1892, but those made at Laramie in 1893 and 1894 are omitted from this report, as they were incomplete and inaccurate. At Wheatland a careful series of measurements were made for us in 1893 by Mr. M. R. Johnston, superintendent of the substation at that place. The data at hand not before published, which was obtained by measurements at Wheatland in 1893 and at Laramie during the years 1895 to 1898, inclusive, are reported below. All the computations have been reduced to the acre standard. The measurements were made on areas varying from a fraction of 1 acre to 50 acres.

HAY CROPS.

The larger part of the land irrigated in Wyoming is for the production of winter stock food, and the amount of water used in the production of hay crops is of great interest and importance. The following gives the results of our measurements on hay land up to the present time:

Duty of water, hay crops.

Crop.	Place.	Year.	Water received by irrigation per acre.		Depth of water supplied land by irrigation and rainfall.		Duty of 1 second-foot for season.		Yield per acre.
			Quantity.	Depth over surface.	Growing season.	Year.	Four months	Ninety-five days.	
			Cu. ft.	*Feet.*	*Feet.*	*Feet.*	*Acres.*	*Acres.*	*Pounds.*
Alfalfa, two crops.	Laramie....	1896...	47,356	1.09	1.49	2.02	224.4	173.2	4,664
Alfalfa, first year.	......do......	1898...	129,388	2.97	3.35	3.61	82.1	63.4	2,220
Alfalfa, two crops.	......do......	1898...	113,101	2.60	2.98	3.24	94	72.6	8,668
Alfalfa, three crops	Wheatland.	1893...	113,184	2.60	2.75	3.13	93.9	72.5	15,752
Brome grass, first year.	Laramie....	1898...	129,811	2.98	3.36	3.62	81.9	63.2	....
Native hay.......	......do......	1898...	174,240	4	4.38	4.64	61	47.1	....
Oats and vetch...	......do......	1898...	68,753	1.58	1.96	2.22	151.7	119.4	5,563
Timothy..........	Wheatland.	1893...	102,384	2.35	2.50	2.88	103.8	80.2	2,212

With one exception the duties determined are on cultivated hay crops. In every instance the irrigation was by flooding the land at intervals through the season. As a rule, hay crops occupy the land permanently, have a long season of growth, and require more water than common farm crops. While the ground is shaded the larger part of the time, which prevents excessive loss by evaporation from the

ground, no method of cultivation to hold the moisture in the soil can be practiced, and large amounts of water are evaporated from the plants, which cover the entire land surface.

It will be noticed that alfalfa, the first year after the seed was planted, received more water than that which had occupied the land more than one year. Newly plowed ground absorbs a large amount of water and frequent irrigations are necessary the first season to get the young plants established. At Laramie in 1896 a small amount of water was used on the alfalfa. The yield that year was also comparatively small and it is not unlikely that more water would have increased the crop. At Laramie only two crops can be cut in a season, while three crops are obtained at Wheatland. As a rule, alfalfa requires more water than cultivated crops other than hay, but is not watered so much as native meadows. The measurement of water used on native hay reported in the table was made on a private farm near Laramie. It was the first year the native sod was irrigated to turn it from pasture to meadow, and while a large amount of water was used it is probable that under the conditions none too much was applied. The grass made good growth, some of it being heavy enough for hay. The soil is composed of loose gravel and sand, extending to a depth of about 10 feet. The water runs through and drains off from below with great rapidity and ease, so it is necessary to irrigate often to keep the surface soil sufficiently moist to force a growth of the native grasses. Seepage through this soil is so great that while water was applied to only 48.9 acres a good crop of wheat was raised with only a partial irrigation and crops of oats and potatoes with no direct application of water, they being supplied by seepage from the ditches and adjacent land. The area of land actually supplied with water was 52 acres, enough being used to cover the total area to a depth of 3.76 feet. Computing the duty of 1 second-foot for four months on this basis would raise it to 65 acres. It should be stated that large amounts of water are needed for the first few years to stimulate native sod so it will produce sufficient crops of hay to be harvested. After the land begins to produce good crops, however, the amount of water and the method of applying it must be modified with some judgment. Often too much water is used on old meadows, being run over the land continuously. All our farmers admit that the low places on their land which receive the most water become filled with "water grass" (species of Beckmannia, Sporobolus, Spartina, Panicularia, Elymus, Catabrosa, Deschampsia, Distichlis, etc.), or "wire grass" (Juncus), or "three-cornered grass" (Carex), or foxtail (Hordeum), few of which make first-quality hay, and on many ranches the greater part of the hay produced consists of these inferior kinds. The better upland grasses are simply drowned out by the excess of water or killed by the accumulation of alkali salts on the surface. The best irrigators give

FIG. 1.—BONANZA OATS FLOOD-IRRIGATED ON THE WYOMING EXPERIMENT STATION FARM. RECEIVED 22.8 INCHES OF WATER.

FIG. 2.—VARIETIES OF GRAIN FURROW-IRRIGATED AT THE WYOMING EXPERIMENT STATION. RECEIVED 18.36 INCHES OF WATER.

the land a thorough soaking, being careful not to let too much accumulate on the lower portions, then turn it onto an adjoining field, allowing the first land irrigated to have a growing and "breathing spell," alternately irrigating one field after another until all have received from four to eight soakings in the season.

On account of the short growing season none of the perennial hay plants will produce a full crop the first season from seed. Alfalfa will produce a small crop the first summer, but as a rule it takes more than one season to secure profitable crops of alfalfa, native hay, or other permanent forage plants. The brome grass, on which measurements were made in 1898, took a comparatively large amount of water; but being the first year from seed, a sufficient crop to pay for harvesting was not produced. The amount of water used on timothy at Wheatland is of interest, and oats and vetch for hay at Laramie produced a good crop with only a comparatively small amount of water.

GRAIN CROPS.

All the duties determined since 1892 for different kinds and varieties of grains (Pl. III) are given in the following table:

Duty of water, grain crops.

Crop.	Place.	Year.	Water received by irrigation, per acre.		Depth of water supplied land by irrigation and rainfall.		Duty of 1 second-foot for season.		Yield per acre.
			Quantity.	Depth over surface.	Growing season.	Year.	Four months.	Ninety-five days.	
Barley:			*Cubic feet.*	*Feet.*	*Feet.*	*Feet.*	*Acres.*	*Acres.*	*Pounds.*
Three varieties	Wheatland	1893	39,744	0.91	1.06	1.44	267.4	206.5	864
Nine varieties	Laramie	1895	52,895	1.21	1.88	2.14	200.9	155.1	896
Highland Chief	...do	1898	117,711	2.70	3.08	3.34	90.3	69.7	1,392
Corn, Minnesota King	Wheatland	1893	47,520	1.09	1.24	1.62	223.6	172.7	3,189
Oats:									
Giant Side	...do	1893	76,896	1.77	1.92	2.30	138.2	106.7	1,603
Early Archangel	...do	1893	68,256	1.57	1.72	2.10	155.7	120.3	1,024
Lincoln Surprise Bonanza	Laramie	1898	82,647	1.90	2.28	2.54	128.6	99.2	*a*1,688
Lincoln (on sod)	...do	1898	112,579	2.58	2.96	3.22	94.4	72.9	698
Surprise (subsoiled)	...do	1898	160,835	3.69	4.07	4.33	66.1	51	1,634
Rye:									
Spring	Wheatland	1893	56,160	1.29	1.44	1.82	189.2	146.2	974
Winter	...do	1893	38,448	.88	1.03	1.41	276.4	213.5	739
Spring	Laramie	1898	58,123	1.33	1.71	1.97	182.8	141.2	556
Wheat:									
White Russian	Wheatland	1893	69,984	1.61	1.76	2.14	151.9	117.3	1,962
Fultz Winter	...do	1893	41,040	.94	1.09	1.47	258.9	200	486
Five varieties	Laramie	1898	158,001	3.63	4.01	4.27	67.3	51.9	*b*1,573

a Average yield of the three varieties. *b* Average yield of the five varieties.

There is a considerable variation in the duties on the same kind of grain due to various causes, such as difference in soils, in location and climate, and other modifying influences. No doubt much of the variation shown in this table (and in others as well) is due to pure accident. In giving what he considers a thorough irrigation the irrigator will apply widely different quantities of water at different times or to different fields at the same time. No doubt different amounts have influences, good or bad, on the resulting crop, but without definite knowledge of what these influences may be the irrigator simply uses his judgment as to the number of times to irrigate and the amount of water to apply at each irrigation. At Laramie barley was given over twice as much water in 1898 as was applied in 1895. The rainfall was greater in 1895 than in 1898; but the amount was not sufficiently great to balance the quantity of water received by the two crops. In fact, if we take account of the rainfall, the crop of 1898 received more than 1 foot of water in excess of that in 1895. There was an increase in the yield with the heavier irrigation, but not a proportional one.

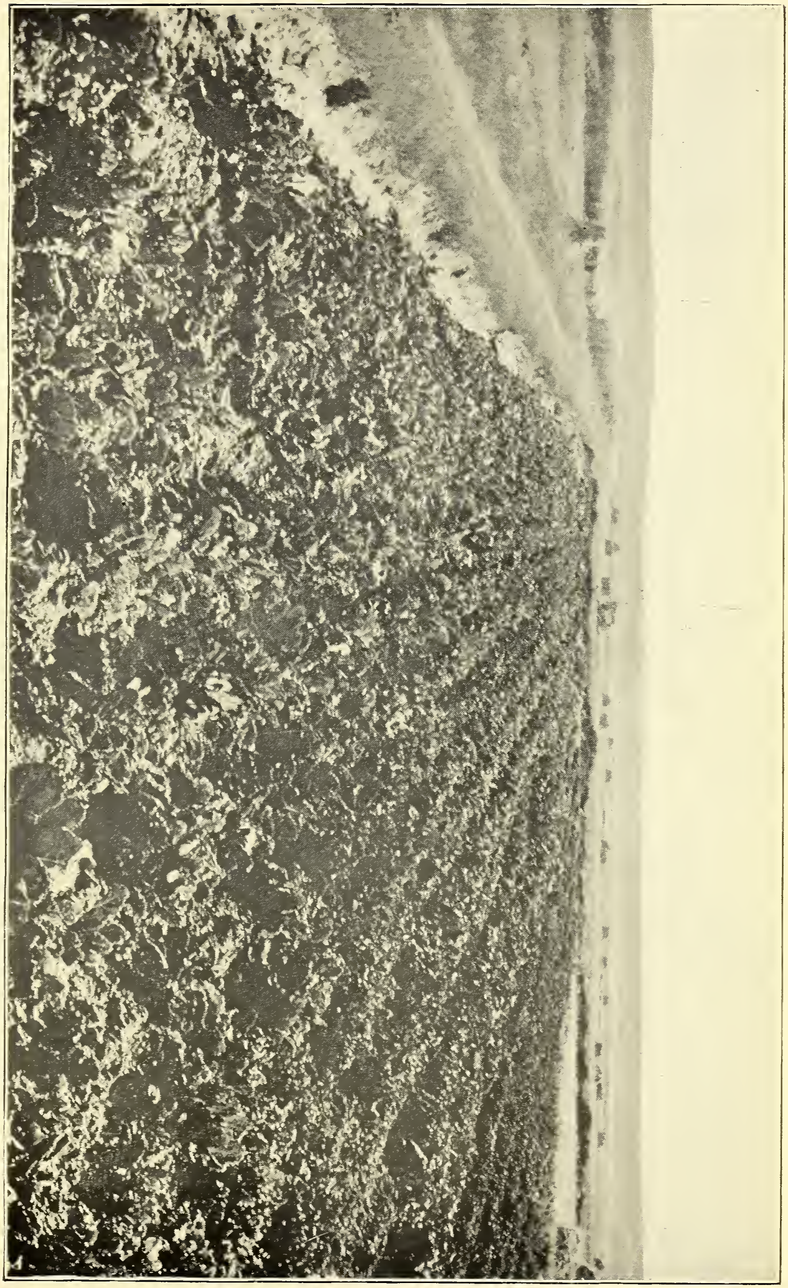
At Wheatland in 1893 the amount of water applied to two different varieties of oats varied by nearly 2½ inches in depth. The variation in amount of water used on different soils is very marked, and will be considered under a separate head.

The difference in the amount of water used on winter and spring grains is well brought out in the table. Winter rye at Wheatland received only two-thirds as much water as spring rye, and the difference is about the same between the amounts applied to winter and spring wheat. Grains planted in the fall may be kept alive by the scanty moisture through the winter months and be brought to early maturity by the heavier rainfall of the spring months along with a little irrigation. Our climate is so dry that winter grain is very uncertain, and when it does not actually die out in the winter only small crops are obtained. Winter rye is sufficiently hardy to do very well, but winter wheat is not a profitable crop.

The average depth of water used on grains where more than one measurement has been made, in Wyoming, including the measurements at Wheatland and Laramie before 1892 and those in the table on page 33, are as follows:

	Feet.
Barley	1.61
Oats, 7 measurements	2.22
Rye, 2 measurements	1.31
Wheat, 2 measurements	2.62

Oats and wheat require more water than either barley or rye, and no doubt rye can be produced with less water than any of the other cereals.



SUGAR BEETS FURROW-IRRIGATED AT THE WYOMING EXPERIMENT STATION. RECEIVED 19.2 INCHES OF WATER.

ROOT CROPS.

The only root crops on which duties have been determined are potatoes, turnips, and sugar beets (Pl. IV). The results of measurements on these crops are as follows:

Duty of water, root crops.

Crop.	Place.	Year.	Water received by irrigation, per acre.		Depth of water supplied land by irrigation and rainfall.		Duty of 1 second-foot for season.		Yield per acre.
			Quantity.	Depth over surface.	Growing season.	Year.	Four months.	Ninety-five days.	
			Cubic feet.	*Feet.*	*Feet.*	*Feet.*	*Acres.*	*Acres.*	*Pounds.*
Potatoes	Laramie	1895	11,683	0.27	0.95	1.20	909.6	702.6	9,000
Do	do	1896	13,866	.32	.72	1.22	766.5	592	
Do	do	1897	26,237	.60	1.01	1.60	405	312.8	
Potatoes, 3 irrigations.	do	1898	49,825	1.14	1.54	1.78	213.3	164.7	8,675
Potatoes, 2 irrigations.	do	1898	12,925	.30	.68	1.94	822.2	635	5,131
Potatoes, 22 varieties.	Wheatland	1893	61,776	1.42	1.57	1.95	172	132.9	7,344
Sugar beets and ruta-bagas.	Laramie	1898	69,875	1.60	1.98	2.24	152.1	117.8	
Sugar beets, 4 varieties.	Wheatland	1893	107,128	2.46	2.61	2.99	99.2	76.6	12,912
Turnips and ruta-bagas.	Laramie	1895	112,733	2.59	3.27	3.52	94.3	72.8	

These crops were all irrigated in furrows, so the water used reached the plant roots from the sides of the furrow or from below, without allowing the water to come against the stem or top of the plant. It will be noticed that potatoes received comparatively small amounts of water, while sugar beets and turnips were much more heavily irrigated. In all the instances reported in which potatoes did not receive more than three-tenths of a foot of water, the irrigation can be considered only a partial watering of the land and crop. A complete irrigation or thorough soaking of the soil can not be done with such small amounts of water, at least under our conditions. By proper cultivation and management we have succeeded in raising very good crops of potatoes on the Laramie plains without irrigating the crop, though it was on old land which had been irrigated in previous years, and which undoubtedly contained considerable surface water. From the table it appears that there has been quite a steady increase in the amount of water used on potatoes at Laramie, and in the same year there was a marked increase in the yield of a plat receiving 1.14 feet of water over the plat which received only 0.3 foot. Too much water, however, is very injurious to the quality of potatoes; so much so that Laramie merchants refuse to buy potatoes known to have been raised on land which is kept too wet. In the measurements reported, however, we have no evidence that too much water was applied.

MIXED CROPS.

It has not been found practicable to measure the water used on each separate plat or field, and often several kinds of crops have been grown on the same plat, all of which were irrigated at the same time. Usually we have kept separate records of the water used on each kind of crop. For instance, we often irrigate several kinds of grain at the same time and keep a record of the amount of water used for the whole. The results of measurements for mixed crops are given in the table below. This table also contains the duties for different crops of peas and flax.

Duty of water, mixed crops—Grains, peas, and flax.

Crop.	Place.	Year.	Water received by irrigation, per acre.		Depth of water supplied by irrigation and rainfall.		Duty of 1 second-foot for season.	
			Quantity.	Depth over surface.	Growing season.	Year.	Four months.	Ninety-five days.
			Cu. feet.	*Feet.*	*Feet.*	*Feet.*	*Acres.*	*Acres.*
Grains, root crops, hay, and garden.	Laramie	1895	50,266	1.15	1.82	2.08	211.4	163.3
Wheat, 18 varieties; oats, 3 varieties.	do	1896	52,895	1.21	1.61	2.11	200.9	155.2
Barley, oats, and wheat	do	1896	63,296	1.45	1.85	2.35	167.9	129.7
Garden (furrow irrigated)	do	1896	54,270	1.25	1.65	2.15	195.8	151.2
Grain (wheat, oats, barley, furrow irrigated).	do	1896	61,122	1.40	1.80	2.30	173.9	134.3
Wheat and oats (sod land)	do	1896	41,886	.96	1.36	1.86	253.7	196
Wheat (Blount No. 16), oats (Lincoln).	do	1897	107,012	2.46	2.87	3.46	99.3	76.7
Oats, rye, barley, and flax	do	1897	69,345	1.59	2	2.59	153.4	118.4
Grain (varieties furrow irrigated).	do	1897	66,467	1.53	1.94	2.53	159.9	123.5
Oats (Surprise and grains furrow irrigated).	do	1898	67,477	1.55	1.93	2.19	157.5	121.6
Wheat (Blount No. 16), oats (Lincoln).	do	1898	75,853	1.74	2.12	2.38	140.1	108.2
Peas	do	1897	74,699	1.71	2.12	2.71	142.3	109.9
Do	do	1897	136,408	3.13	3.54	4.13	78	60.2
Do	do	1898	124,304	2.85	3.23	3.49	85.5	66
Barley (Highland Chief), wheat (Scotch of Scotch).	do	1898	75,159	1.73	2.11	2.37	141.4	109.1
Oats, rye, barley, and flax	do	1897	69,345	1.59	2	2.59	153.3	118.4
Flax, 2 varieties	Wheatland	1893	95,040	2.18	2.33	2.71	111.8	86.4

In 1895 but few separate records were kept, but the total amount used on the station farm was determined and shows that enough water was used to cover all the land cultivated to a depth of 1.15 feet. The season of 1895 was unusually favorable at Laramie, all crops succeeded well, and only small amounts of water were used. The irrigation was by flooding for grains and hay and by the furrow method for root crops and garden.

In most instances where different grains are reported together, they were occupying the same field, which was all irrigated at one time and each crop received the same amount of water; so where wheat and oats, or wheat, oats, and barley are reported together, the duty is the same for each crop as it is for the combined crops. Unless otherwise stated the grains were irrigated by flooding. Where cultivated grain is

mentioned it refers to varieties of wheat, oats, and barley, which were planted with drills twice as far apart as the ordinary drill row and cultivated between the rows after each irrigation. These cultivated grains were irrigated by the furrow method. (Pl. III, fig. 2.) The garden duties reported in this table consisted of mixed garden crops such as peas, beans, celery, beets, turnips, lettuce, cabbage, etc.; and the duty for the garden represents the amount of water necessary for such crops. Yields are not given in this table, but no measurements are reported on land which failed to produce and mature a crop.

The duties given in this table, if we leave out the individual crops of peas, are more uniform than those given in the preceding table for single crops. As a rule these duties were determined from measurements of larger areas than those on separate crops, and it is likely that they more nearly represent the amounts of water which are used in average farm practice. Averages from the table give a duty of 154.6 acres for a continuous flow of 1 cubic foot per second for four months, or enough water used to cover the land to a depth of 1.578 feet.

CONDITIONS AFFECTING DUTY.

INFLUENCE OF CLIMATE AND RAINFALL ON DUTY.

The amount of water which must be applied to the land artificially in order to produce crops varies from none, where the rainfall is sufficiently great, to the maximum amount needed by soil and crop where there is practically no rainfall. As already stated, there is much variation in the quantity of water which is necessary for the same kind of plants growing in different places on the earth's surface. No doubt much may be done for the arid region of the West by introducing useful plants from other arid countries and by the actual production of varieties which will succeed with small amounts of moisture. A beginning has been made, and already we have drought-resisting wheat, short-season oats, and nonsaccharine sorghums which mature with little moisture, the Turkestan alfalfa, which withstands drought better than the common variety, and there are numerous plants growing on our dry plains which may become valuable when brought under cultivation. The West is still new, and the plants usually grown are those which have been introduced from humid regions. Such plants require comparatively large amounts of water supplied by irrigation. As varieties are produced which require less water the area which can be irrigated with the supply will be extended.

INFLUENCE OF METHODS OF IRRIGATION ON DUTY.

There are various methods of applying water to crops, which have been classified as flooding, furrow, bed, check, rill, seepage, and pipe, or subirrigation, systems. The amount of water required to mature

the plant remains the same, but there is considerable difference in the amount of waste in distribution, depending on the method by which the farmer furnishes the water to the plant. Whether one method is more efficient and economical than another depends upon a number of conditions, as kind of crop, slope and configuration of the land, kind of soil and subsoil, and the care and skill used in applying the water.

Subirrigation, where the water is applied to the lower layers of the soil by underground systems of pipes, is generally considered the most economical, as it eliminates two sources of loss—waste by running off from the surface and evaporation from open ditches. Two systems of subirrigation, one with iron pipe and the other with lines of porous tile laid deep enough in the soil to be below the plow, are in use at the Wyoming Station, but unfortunately the amount of water used in them has not been accurately measured. Our observation leads us to believe, however, that where the subirrigation pipes are located in loose, gravelly, and sandy subsoil the loss from seepage is greater than the ordinary losses observed when water is applied through open ditches. Systems of subirrigation have the advantage in requiring little care, and undoubtedly such systems are ideal where the surface soil absorbs water readily and allows its distribution to some distance from the pipe, and where the subsoil is such as to prevent great loss from seepage. The duty of a second-foot in pipe systems in California is said to be 500 acres and over.

By far the greater number of crops seem to thrive better when water is not allowed to come against the crown of the plants. Even plants, such as celery and cabbages, which are said to thrive in a saturated subsoil, are not benefited by standing directly in the flood, and potatoes, corn, tomatoes, and other plants show unmistakable injury if the water is allowed to come in contact with the stalks where they emerge from the ground. A matter of common observation is that grass and grain, which are usually irrigated by flooding, produce more thrifty growth on ditch banks and higher ridges and knolls where the roots are supplied by seepage from beneath rather than from flooding the surface. This fact has led in some localities to the adoption of the rill system with such crops as cover all the land. The rills or small streams are laid out on contour lines with a corn marker or other implement which will produce small parallel ditches, and the water is allowed to run through them for several days at a time until the land is well saturated. Tests of this method have shown that it is not practicable to irrigate thoroughly by means of it without a large waste at the lower side of the field. This system is practiced in parts of central Wyoming where there is abundant water supply. After the water has been distributed to the laterals little attention is required.

The bedding system is usually considered a very old and out of date, but somewhat economical, method of irrigation. After the dikes or

levees have been thrown up around each level field, at great labor and expense, little skill and attention are required further than to turn the water from one plat into another after it has stood a sufficient time to thoroughly wet the land. The check system, in which low dikes extend along the contour lines to facilitate flooding the land and prevent rapid waste of water, is an improvement on the bed system, at least for large areas.

Flooding is the system more generally adopted for such crops as forage plants and grains, which cover all or practically all of the land. The bed and check methods are modifications of flooding. With this system much depends on the configuration of the land and the skill of the operator, and men who become skillful in the application of water command higher wages and are always in demand. Under ordinary conditions the man who understands the business will irrigate with little or no waste. Where the slope is not too great, the surface even, with the soil permeable, and the head water supply adequate, not a drop will be allowed to escape from the land by running off the surface, and the efficiency of the water is as great as it could be under any other system of distribution. With a stiff clay soil, which absorbs water slowly, the head or flow used must be so modified as to allow time for the water to be taken up, but in loose sandy soils a large head is necessary to cover the land as soon as possible. In some instances the soil is so porous that it is necessary to fill it to a considerable depth before the water can be run over the surface, and in such cases large amounts of water are required. On loose or gravelly soil water usually has a small duty.

In furrow irrigation the water is run through channels plowed for the purpose between rows of plants, such as corn, potatoes, and like crops, which are planted sufficient distances apart. In this system it is possible, if so desired, to give partial irrigations—as, for example, by allowing the water to run through every other furrow for so short a time that not all the land between them is supplied. High duties are often obtained in this way, and the crop is said to be irrigated with an amount so small that it would be impossible to soak all the land with it. On the other hand, if the soil is thoroughly soaked at each irrigation, practically as much water is used as in any other method. In 1895 potatoes which were given only one furrow irrigation in the season apparently had a duty of 909.6 acres, while turnips irrigated in the same way gave a duty for four months' flow of only 94 acres. In 1897 and 1898 potatoes were irrigated with an amount of water which would cover the land to a depth of only from $1\frac{1}{2}$ to 2 inches, while a thorough irrigation by flooding under ordinary conditions can probably not be accomplished with much less than 3 inches. In 1898 oats and wheat, planted in rows twice as far apart as with the ordinary drills and irrigated in furrows gave duties of 140 and 157.5 acres,

while that sown as usual and flooded gave duties of 67.3 and 128.6 acres, respectively. Furrow-irrigated grain gave a duty of 160 acres in 1897 and 174 acres in 1896. Higher duties than this were obtained with flooded grains in 1896, but in other years they were appreciably lower by this method. These results are not conclusive; but if the furrow irrigation is done in such a manner that there is no waste, we would expect higher duties, because the after cultivation of the land following furrow irrigation prevents much of the loss by evaporation. The above furrow-irrigated grains were regularly cultivated after each irrigation, just as is done with potatoes or garden crops. Any method which prevents loss occurring in any way, except through the plant itself, should increase the duty of water applied.

CONDITION OF THE SOIL.

General remarks have been made elsewhere in regard to the effect of the kind, slope, and evenness of the land on the amount of water necessary. It is the general belief that sod land needs more water than that which has been cultivated for a number of years, an opinion which is sustained by the investigations at the Wyoming Experiment Station. The land of this station, upon which water measurements have been made for the past eight seasons, was native sod, broken in the spring of 1891. The average duty of water for all crops on this land for each year since 1891 for which trustworthy records were made is shown in the following table:

Average duties on new and old land at the Wyoming Station.

1891.		1892.		1895.		1896.		1897.		1898.	
Duty.	Depth [a] of water.	Duty.	Depth of water.	Duty.	Depth of water.	Duty.	Depth of water.	Duty.	Depth of water.	Duty.	Depth of water.
Acres.	*Inches.*	*Acres.*	*Inches.*	*Acres.*	*Inches.*	*Acres.*	*Inches.*	*Acres.*	*Inches.*	*Acres.*	*Inches.*
95.6	36.76	216	20.49	211.5	21.94	272.8	18.14	173	27.03	162.4	30.62

[a] Irrigation and rainfall.

It will be noticed that the smallest duty for any year after 1891—that for 1898—is nearly 59 per cent greater than for the first year the land was cultivated. The decreased duty in 1897 and 1898, as compared with the immediately preceding years, is traceable to the extra amount needed for subsoiled land and to the fact that some sod land was broken and cropped to oats the last season. One acre of sod land was planted in 1896 and one-half acre subsoiled.

Some observations have been made to show the influence of subsoiling. The duty of water for barley on subsoiled land was 196.8 acres; on land not subsoiled, 200.8 acres. The yield of barley was

increased at the rate of 33 pounds per acre. oats increased 1.75 pounds per acre. and wheat decreased 54 pounds per acre on subsoiled land.

In 1898 a little over one-half acre was subsoiled and planted to oats. The soil of this plat was practically the same from the surface to a depth of 5 feet. at least. except that the first 8 inches was in a good state of tilth from eight years' irrigation and cultivation, and at a depth of 8 inches the subsoil, consisting of a light-colored mixture of lime, gypsum, clay, and sand, was very compact and almost impervious to water. The subsoiling thoroughly broke up 8 to 10 inches of this subsoil, so that it would readily absorb water. At the first irrigation (June 27) the soil drank up so much water that it seemed almost impossible to satisfy it, and enough was applied to cover the land 30.84 inches deep. After this irrigation a man could not walk on the plat without miring. Another irrigation was given on July 11 of 13.44 inches, which, with the 4.59 inches of rain which fell during the season, made a total of 48.87 inches. The yield was 51 bushels per acre. The duty for this plat was 66.1 acres, while the duty obtained with oats on sod was 94.3 acres, and on old land was 128.5 acres. The duty in 1898 on land one-half of which was subsoiled in 1896 was 141.4 acres.

Subsoiling is advocated in the semihumid region to increase the storage capacity of soils for the water from winter snows and thus to save it for the coming crop. Under arid conditions there is so little moisture to be absorbed in the winter that subsoiling has the opposite effect. It stores irrigation water during summer to supply evaporation during the dry winter.

ALTITUDE.

Variation in the amount of water required on the different soils makes it impossible to trace observed differences in duty to the effect of altitude alone. The effect of altitude on some conditions which directly affect duty has been observed. The simple fact that decrease of atmospheric pressure increases evaporation illustrates the point. Direct measurements of evaporation from water surface, made at Fort Collins[1] and Laramie, show a marked increase in the amount lost at the higher altitude. The two places are less than seventy miles apart. The evaporation tank used for the measurements at Laramie was, in round numbers, 2,150 feet above that at Fort Collins. The following table gives the averages of these measurements for six years (1892–1897), during which time unbroken series of measurements were obtained at both places. The evaporation given is the average of six years' measurements for each month.

[1] Colorado Sta. Bul. 49.

Difference in evaporation at different altitudes, 1892–1897.

Place.	June.	July.	August.	September.	Total for four months.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Laramie (7,150 feet above sea level)	7.56	7.98	6.77	5.53	27.84
Fort Collins (5,000 feet above sea level)	4.80	5.21	6.07	4.21	20.29
Difference	2.76	2.77	.70	1.32	7.55

This table shows an average loss at an altitude of 7,150 feet of over seven and one-half inches more than at 5,000 feet altitude for the four summer months. How much of this difference is due to decrease in atmospheric pressure, and how much to differences in temperature, relative humidity, and wind movement, can not be stated at this time. There is greater wind movement at Laramie, but the temperature is lower, while the difference in humidity at the two places is not great. Whatever be the cause, the greater loss at the higher altitude must be made up by applying more water to the land, unless it can be shown that crops at a high altitude actually need less water to mature them. It has been shown that decrease in atmospheric pressure, other things being equal, increases the amount of water lost by plants through transpiration.[1] The rate of transpiration is affected by so many other conditions, however, such as temperature, humidity, intensity of the light, etc., that, with our present knowledge, we can not say that crops actually need a greater water supply at high altitudes on this account. Our experience indicates that the opposite is the case, at least with some plants. For example, potatoes have produced good crops on the Laramie plains, without irrigation, when the rainfall was so small that it would be entirely inadequate at lower altitudes. In 1898 the yields of potatoes, without irrigation, on land which had been irrigated the year before, ranged from less than 100 bushels to over 500 bushels, depending on the way they were fertilized. A comparison of duties obtained with other crops as well as with potatoes indicates that the greater the elevation the less the amount of water required.

THE IRRIGATING SEASON.

A clear understanding of the amount of water required to mature crops is not all the information needed by those engaged in irrigation farming. A knowledge of the time in the year the water must be applied to the land is equally important and is as closely related to the question of supply and demand. The irrigating season and the growing season are not necessarily closely related to one another, for water sufficient to mature a crop may be brought to the land during the fall, winter, or spring, when no plants are growing thereon. How-

[1] See Wyoming Sta. Bul. 15.

ever, irrigation is generally applied directly to the crop during some part of its period of growth. When water should be so applied depends on the supply, the amount and distribution of the rainfall, the nature of the soil, and the kind of crop. The irrigation of any crop during the season is intermittent, and experienced farmers appreciate the value of an abundant supply of water always available, so that it may be supplied to the thirsty soil and crop whenever conditions indicate the need.

The length of the irrigating season and the amount of water needed in each portion of it are matters of the first importance in determining the amount of land which may be reclaimed by the available supply and in making just and equitable apportionment of the water among users.

LENGTH OF THE IRRIGATING SEASON VARIES.

The length of the irrigating season is as variable for different crops and different systems of irrigation practice as is the amount of water required. To obtain the consensus of opinion in regard to what should constitute the irrigating season, questions were sent to fifty representative ranchmen and farmers in Wyoming. They were asked what crops they irrigated, and what months and parts of months constituted the irrigating season. Some of the replies were as follows:

Two men who irrigated potatoes, grain, and hay gave the season as June, July, and August. Three persons who irrigated hay, grain, and fruit defined the season as May, June, July, and August. A farmer in Sheridan County irrigates grain, alfalfa, and hay grasses during June, July, August, and the first half of September; while another in the same section, who grows the same crops, and in addition potatoes, corn, strawberries, and orchard fruits, irrigates in June, July, and August, and sometimes through October. A farmer on the eastern border of the State, raising general crops, says that the season extends from May 15 to September 1. One farmer in the northern and another in the southern part of Wyoming, who irrigate wheat, oats, potatoes, and hay, state that they use water from May to August, and sometimes in September; still another uses water in April, May, and June. Four ranchmen, who irrigate mostly for the production of native hay, say the water is used from the middle of May to the middle of July, and another names the months May, June, and July. A farmer in northern Wyoming, irrigating hay, grain, and small fruits, uses water from May to November 1, and another in the southern portion, who raises general crops, including alfalfa, grain, vegetables, potatoes, and native hay, applies water from April to November, the month of maximum use varying between July, August, and September. A number of ranchmen on the Laramie plains who irrigate native hay do the most of their irrigating between the middle of April and the middle of July.

One of these says he does some fall irrigating and he believes he can make beneficial use of the water for the period from April 15 to November 15. One man on the Laramie plains has no irrigating season, but applies the water through the entire year, running it over the land when and where he can in the winter as well as in the summer time. The land irrigated in the winter is covered from 1 to 2 feet deep. This land is not again irrigated during the year, and yields about three-fourths of a ton of native hay per acre.

For individual crops the time between the first and last application of water is sometimes very short. Where a crop is produced with a single irrigation the water may all be applied in one or two days, depending on the area and the method of running on the water, and where more than one irrigation is given only a few days may intervene. A few instances from actual practice will illustrate. The time between the first and last application of water to native hay on a ranch near Laramie in 1898 was ninety-four days. On the experiment station farm ninety-five days intervened between the first and last irrigation of alfalfa (which also represents the time from the first to the last irrigation on the entire farm), fifteen days with rye, from fourteen to sixty-nine days for different plats of oats, from nineteen to thirty-eight days with wheat, twenty-nine days with peas, fifty-one days with sugar beets, twenty-eight days with potatoes, and as few as thirteen days with barley. Such intervals of time represent the season during which application of water was made to the different crops. It will be noticed that the period varies greatly for the same kind of plants on different fields in the same summer. This variation may be influenced by such natural causes as rainfall, condition of the soil, and the length of time required for the variety being cultivated to reach maturity, but it is largely due to the opinion of the farmer as to when and how often applications of water are needed and to limitations in his ability to apply the water at a given time. Two fields may appear to need water on the same date, but two or three weeks may pass after beginning the irrigation of one before water can be turned on the other. The length of time between the first and second or between the second and third irrigations is equally uncertain, although with some crops, such as potatoes or fruits, the irrigations follow each other with great regularity, after having been begun. It seems to be the general opinion that for these crops the soil should not be allowed to dry out after the first irrigation till they have completed their growth and the time of ripening is reached.

SEASON OF USE AND OF GREATEST SUPPLY.

The relation of the water supply to the time of use is a most intimate one. Without reservoirs for storage the time of use is defined by the flow in the streams furnishing the supply. Fortunately, over a large

part of the arid region the streams on which irrigation depends have their sources in high snow-clad mountains and in forested areas at these high altitudes. These are the great natural reservoirs which furnish a practically perennial supply, and from which the maximum discharge occurs at the beginning of the growing season and occasionally approximately close to the time the largest amount is needed on the dry plains below. Where the streams are torrential in character as is usually the case if they head in barren uplands or in deforested mountain areas, the supply is uncertain and the time during which the flow continues is short. It often occurs that a stream has water in it for so brief a period that little use can be made of it for irrigation. In such cases storage is the only solution. With no means of holding the supply until it is needed the irrigating season is not long enough to mature a variety of crops, if, indeed, enough water can be obtained to mature any plants at all. To supply the crop the irrigator under such conditions must use the water when it comes, regardless of the then existing needs of the plants, and let the soil store up what it will. Much of the supply in the Southwest, including parts of New Mexico, Arizona, and Texas, comes from torrential streams, and the time of greatest flow is, unfortunately, not the time of greatest need. In the Dakotas and Kansas, where artesian and other wells are used for irrigation, the supply is continuous, but as a rule is so small that some means of storage is necessary in order to obtain a sufficient head to irrigate large areas. In the other irrigated States, including Colorado, Wyoming, Montana, and Utah, the main streams, as a rule, are perennial in character and the time of greatest supply is extended through a considerable portion of the growing season. In many instances streams which were once perennial have become torrential by the destruction of the forests over their catchment areas, and in all such cases the mountain storage of snow and ground water must be supplemented by artificial storage before the greatest development can be brought about.

Out of twenty-three answers made by ranchmen in different parts of Wyoming to the inquiry, "In what month do you need the largest amount of water?" thirteen replied that the greatest amount was needed in June, seven said their greatest need was in July, and the others stated that it was in July, August, and September. In general, the principal crop irrigated by those who need the largest amount in June is native hay, the use of water in other cases being largely for alfalfa, grain, vegetables, and fruit. The answers to the question, "In what month in the irrigating season do you use the smallest amount of water?" are equally divided between May, August, and September, while one stated that his smallest use was in October; and another, an excellent and most intelligent farmer, in northern Wyoming, stated that he used the least water in June and the most in July, on wheat, oats, alfalfa, and grass. The water measurements which

have been made give some definite information regarding the time of maximum use in the localities where they have been carried out. The following table and Plate VIII give in detail the amount of water used and the time of its use through the season for each crop upon which water measurements were made at Wheatland in 1893. To show the actual growing season of each crop, the dates planted and harvested are also reported.

The distribution of irrigation throughout the season at Wheatland, Wyo., 1893.

Crop.	Date planted.	Date irrigated.	Water applied per acre at each irrigation. Quantity.	Water applied per acre at each irrigation. Depth over surface.	Total water per acre. Quantity.	Total water per acre. Depth over surface.	Depth of irrigation and rainfall for season.	Date harvested.
			Cu. ft.	*Feet.*	*Cu. ft.*	*Feet.*	*Feet.*	
Alfalfa	June, 1891	Apr. 18	31,104	0.71	113,184	*a* 2.60	2.86	July 5
		June 23	19,008	.44				Aug. 9
		July 12	14,256	.33				Sept. 16
		July 25	22,032	.51				
		Aug. 12	14,256	.33				
		Sept. 1	12,528	.29				
Barley, 3 varieties	Apr. 3	June 8	17,280	.40	39,744	.92	1.07	July 29
		June 20	12,528	.29				
		July 4	9,936	.23				
Corn, Minnesota King	May 12	July 3	12,096	.28	47,520	1.09	1.23	Sept. 24
		July 22	18,144	.42				
		Aug. 7	17,280	.40				
Flax (White Russian Belgian)	Apr. 25	June 14	34,560	.79	95,040	2.18	2.33	Aug. 8
		June 27	22,464	.52				
		July 8	38,016	.87				
Oats, Giant Side	Apr. 14	June 2	30,672	.70	76,896	1.77	1.92	Aug. 16
		June 9	15,984	.37				
		June 21	14,256	.33				
		July 4	15,984	.37				
Oats, Early Archangel	Apr. 13	June 5	19,008	.44	68,260	1.57	2.10	Aug. 29
		June 15	20,308	.47				
		July 5	21,168	.49				
		July 20	7,776	.18				
Potatoes, 22 varieties	May 15	June 24	9,072	.21	61,776	1.42	1.55	Oct. 16
		July 8	9,504	.22				
		July 18	7,776	.18				
		July 24	13,824	.32				
		Aug. 4	10,368	.24				
		Aug. 17	11,232	.26				
Rye, spring	Mar. 29	June 5	22,896	.53	56,160	1.29	1.43	July 20
		June 19	21,600	.50				
		June 30	11,664	.27				
Rye, winter	Oct. 6, 1892	June 2	25,488	.59	38,448	.88	1.02	July 15
		June 17	12,960	.30				
Sugar beets, 4 varieties	May 4	June 17	31,104	.71	107,128	2.46	2.60	Aug. 6
		June 26	22,464	.52				
		July 8	15,552	.36				
		July 19	20,728	.48				
		July 31	17,280	.40				
Timothy	May, 1892	May 10	25,488	.59	102,384	2.35	2.48	July 22
		May 30	18,576	.43				
		June 10	20,304	.47				
		June 23	20,304	.47				
		June 28	17,712	.41				
Wheat, White Russian	Mar. 29	June 3	30,672	.70	69,984	1.61	1.76	Aug. 3
		June 17	15,984	.37				
		June 30	11,664	.27				
		July 7	11,664	.27				
Wheat, Fultz winter	Oct. 3, 1892	June 2	25,488	.59	41,040	.94	1.08	July 25
		June 17	15,552	.36				

a For the time between first and last irrigation, including 3.22 inches of rain. To the other figures in this column add 4.60 inches of rainfall for depth received by the land during entire year. Total rainfall for the year, 6.42 inches.

With annual crops planted in the spring the first irrigation occurs from one to two months after sowing the seed. Winter grain planted in the fall receives no water by irrigation till late the next spring, when enough is applied in one or two small irrigations to mature the crop. Hay crops may be irrigated as early as April or May, but as a rule irrigation of cultivated crops does not begin till June, or in some cases till as late as July. The table shows that the last irrigation usually occurs about a month before the time of harvest. Water stimulates growth, and it is found necessary to stop irrigating sufficiently early to allow the plants to properly mature before the time of frost. Grains are usually irrigated the last time when beginning to head out. This leaves sufficient moisture in the soil to insure plump grain and gives ample time for it to reach maturity. Where rusts prevail in the grain it has been found that keeping the soil wet after the plants reach full growth—i. e., after they are headed out—stimulates the development of such fungus diseases, but where water is kept away after the time of heading little difficulty has been experienced from rusts. It appears from the results given in the table that more water is supplied at the first irrigation than in later applications. This is probably due to the fact that the land is more porous, as it is nearer the time it was plowed, and also that the soil has become more effectually dried out than it is after once becoming compacted and thoroughly soaked at the time of the first irrigation.

Averages of the amount of water used at Wheatland during each month of 1893 for different crops[1] are given in the table below. In this table the measurements have been reduced to inches in order to make the differences more apparent than would be the case if stated in fractions of a foot.

Monthly distribution of irrigation water at Wheatland, Wyo.

[Depth in inches over surface irrigated.]

Month.	Alfalfa.	Timothy.	Corn.	Barley.	Oats.	Spring wheat.	Winter wheat.	Winter rye.	Flax.	Sugar beets.	Potatoes.	Total.
April	8.57											8.57
May		12.14										12.14
June	5.23	16.07		8.21	11.62	16.07	11.30	10.59	15.71	14.76	2.50	112.06
July	10		8.33	2.74	11.43	3.21			10.47	14.75	8.57	69.50
August	3.93		4.76		*a*2.12						5.95	16.76
September	3.45											3.43

a In 1889 only.

From this table it appears that the greatest amount of irrigation occurs in June for all crops except potatoes and alfalfa, which receive the most water in July, and it indicates that whether a farmer needs the most water in June or July depends on the kind of crop of which he has the largest area.

[1] The averages for oats and potatoes include measurements made by Territorial Engineer Mead in 1889.

The following table gives in detail the distribution of irrigation throughout the season at Laramie for the years 1895 to 1898, inclusive:

Distribution of irrigation throughout the season, Wyoming Experiment Station, Laramie, Wyo., 1895–1898.

Crop.	Date planted.	Date irrigated.	Water used at each irrigation per acre. Quantity.	Water used at each irrigation per acre. Depth over surface.	Total water used for the season per acre. Quantity.	Total water used for the season per acre. Depth over surface.	Depth of irrigation and rainfall for the season.*a*	Date harvested.
1895.			*Cu. ft.*	*Feet.*	*Cu. ft.*	*Feet.*	*Feet.*	
All crops					50,266	1.154	1.829	
Potatoes	May 11	May 24, 25	11,683	0.27	11,683	.27	.944	Sept. 26.
Turnips and rutabagas	May 14	May 27, 28	11,077	.25	112,733	2.59	3.264	Oct. 12.
		June 19	27,682	.64				
		July 6	17,622	.40				
		Aug. 17–19	56,352	1.29				
1896.								
Alfalfa	1894	June 17	24,556	.56	47,356	1.09	1.486	July 7 and Sept. 8.
		July 13	22,800	.52				
Barley (9 varieties)	April 23	June 29	19,749	.45	52,895	1.21	1.606	Aug. 14–28.
		July 24	33,146	.76				
Barley, oats, and wheat	May 5	July 2	41,216	.95	63,296	1.45	1.866	Sept. 12–14.
		July 27	22,080	.51				
Garden (furrow irrigated)		July 3–7	38,745	.89	54,270	1.25	1.666	
		July 30	15,525	.36				
Grain (furrow irrigated)	Apr. 20–24	July 2, 3	28,204	.65	61,122	1.40	1.786	
		July 22, 23	32,918	.76				
Potatoes		Aug. 8–14	13,866	.32	13,866	.32	.716	
Wheat (18 varieties) / Oats (3 varieties)	Apr. 4	June 20 to July 1	33,101	.76	53,981	1.24	1.636	Aug. 29 to Sept. 10.
		July 23–25	20,880	.48				
Wheat and oats (sod land)	May 8	July 31	41,886	.96	41,886	.96	1.356	Sept. 25.
1897.								
Grain *b*	May 1	July 3–5	44,299	1.02	136,408	1.53	1.944	
		July 29	22,168	.51				
Oats, rye, barley, and flax	May 14	June 29, 30	41,265	.95	69,345	1.59	2.004	
		July 28	28,080	.64				
Peas	Apr. 21	June 26	20,093	.46	74,699	1.71	2.124	Oct. 4–6.
		July 30, 31	54,606	1.25				
Do	Apr. 27	July 1–2	96,916	2.22	136,408	3.13	3.544	Oct. 23.
		Aug. 2	39,492	.91				
Potatoes	June 8–12	July 31	19,475	.45	26,237	.61	1.024	Oct. 2–9.
		Aug. 16	6,762	.16				
Wheat (Blount No. 16) / Oats (Lincoln)	Apr. 21	June 25–28	70,560	1.62	107,012	2.46	2.874	Sept. 13–17.
		July 27	36,452	.84				
1898.								
Alfalfa (first year)	May 10, 11	June 18–21	50,431	1.16	129,388	2.97	3.353	July 15 and Sept. 7.
		July 20–22	36,938	.85				
		Aug. 30 to Sept. 3	17,525	.40				
		Sept. 19–21	24,494	.56				
Alfalfa	May, 1894	June 15–18	68,327	1.57	113,101	2.60	2.983	July 14 and Sept. 8.
		July 1–6	24,710	.57				
		July 23–25	10,355	.24				
		Sept. 1, 2	3,617	.08				
		Sept. 15, 16	6,092	.14				
Barley, Highland Chief	Apr. 29	June 29	81,984	1.88	117,711	2.70	3.083	Aug. 30.
		July 11, 12	35,727	.82				
Do	Apr. 18	June 24	41,840	.96	75,159	1.72	2.102	Aug. 29.
Oats, Surprise	Apr. 16	July 13	33,319	.76				Aug. 13.
Wheat, Scotch of Scotch	Apr. 18							Aug. 29.
Brome grass (first year)	May 14	June 29, 30	76,029	1.75	129,811	2.98	3.363	
		July 15	35,390	.81				
		Sept. 1	18,392	.42				
Oats and vetch for hay	May 11	June 23, 24	39,919	.92	68,753	1.58	1.963	Aug. 3. Sept. —.
		July 15	17,046	.39				
		Aug. 31	11,788	.27				
Oats, Surprise	Apr. 20	June 22	36,207	.83	82,647	1.90	2.283	Aug. 16.
Oats, Bonanza	do	July 9–13	36,000	.83				Aug. 25.
Oats, Lincoln	Apr. 23	Aug. 3	10,440	.24				

a Add 3.06 inches (rainfall) for depth received by land during entire irrigation period in 1895, 6 inches in 1896, 7.02 inches in 1897, and 3.04 inches in 1898. The total rainfall for 1895 was 11.15 inches; 1896, 10.75 inches; 1897, 11.99 inches; 1898, 7.63 inches.

b Between 500 and 600 varieties of wheat, oats, and barley planted in rows and irrigated in small furrows between.

Distribution of irrigation throughout the season, Wyoming Experiment Station, Laramie, Wyo., 1895-1898—Continued.

Crop.	Date planted.	Date irrigated.	Water used at each irrigation per acre. Quantity.	Water used at each irrigation per acre. Depth over surface.	Total water used for the season per acre. Quantity.	Total water used for the season per acre. Depth over surface.	Depth of irrigation and rainfall for the season.*a*	Date harvested.
1898.			*Cu. ft.*	*Feet.*	*Cu. ft.*	*Feet.*	*Feet.*	
Oats, Lincoln (on sod)	May 18	June 23	51,517	1.18	112,579	2.58	2.946	Sept. 3.
		July 7	37,410	.86				
		July 28	23,652	.54				
Oats, Surprise (on subsoiled land)	May 10	June 27	111,941	2.57	160,835	3.69	4.073	Aug. 17.
		July 11	48,894	1.12				
Peas	Apr. 16	June 28	72,179	1.66	124,309	2.86	3.243	Sept. 21.
		July 8	32,640	.75				
		July 27	19,490	.45				
Potatoes	May 11	July 7	36,900	.85	49,825	1.15	1.533	Sept. 27.
		July 28	7,425	.17				
		Aug. 4	5,500	.13				
Do	do	July 28	7,425	.17	12,925	.30	.683	Do.
		Aug. 4	5,500	.13				
Rye	Apr. 29	June 21	28,829	.66	58,123	1.33	1.713	Aug. 13.
		July 6	29,294	.67				
Sugar beets and rutabagas	May 24	July 7	50,625	1.16	69,875	1.60	1.983	Oct. 1.
		Aug. 27	19,250	.44				
Wheat, Blount No. 16; Oats, Lincoln	Apr. 16	June 25	35,280	.81	75,853	1.74	2.123	Aug. 29. Aug. 18.
		July 14	40,573	.93				
Wheat (5 varieties)	Apr. 18-22	June 25, 26	74,485	1.71	158,001	3.63	4.013	Aug. 19. Sept. 4.
		July 12	34,846	.80				
		Aug. 2	48,670	1.12				
Wheat, Surprise, and cultivated grain	May 10	June 27	54,460	1.25	67,477	1.55	1.933	Aug. 17.
		July 11-14	13,017	.30				

a Add 3.06 inches (rainfall) for depth received by land during entire irrigation period in 1895, 6 inches in 1896, 7.02 inches in 1897, and 3.04 inches in 1898. The total rainfall for 1895 was 11.15 inches; 1896, 10.75 inches; 1897, 11.99 inches; 1898, 7.63 inches.

From the table it appears that the season of use of water on the Laramie experiment farm is between the latter part of May and the last of September, or a total of about four months. From one to four irrigations are given the same crop, and almost without exception the first irrigation is heavier than later ones.

In 1898 measurements of the water used on a ranch on the Laramie plains showed that the most water was used in June and the least in September. The proprietor of this ranch supplied 52 acres with water, of which 43½ acres were native hay. He used 20.04 inches in June, 9.36 inches in July, 15.6 inches in August, and 0.0192 inch in September. Measurements at the Wyoming Experiment Station in 1895 show the following average amounts used in each month, including all crops:

Average amounts of irrigation water used on all crops during 1895.

	Inches.
May	0.31
June	5.84
July	2.87
August	1.63
September	2.30
October	.65

Enough water was used to cover all the land under cultivation to the depths given each month. In reality, all the land was not irrigated in any one month, and only a small fraction of it received water during any of the months except June. The crops were potatoes, turnips and ruta-bagas, wheat, oats, barley, rye, alfalfa, and general garden crops.

The average depth of water used each month on each crop at Laramie, so far as we have data, is given in the following table:

Average depth of water used each month on various crops at Laramie, Wyo.

Month.	Alfalfa.	Grass.	Peas.	Oats.	Barley.	Rye.	Wheat.	Sugar beets.	Potatoes.	Total.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	
June	13.16	20.50	19.92	15.21	13.16	7.92	13.71	....	....	103.58
July	8.72	9.54	20.52	9.85	11.40	8.04	10.64	13.92	8.82	83.45
August	....	10.32	10.92	1.86	....	....	*a* 13.34	5.28	2.44	42.16
September	7	.20	....	....	....	....	....	....	....	7.20
October	*b* 6	....	....	....	....	....	....	....	....	6

a One plat irrigated in August one year. In six other measurements on wheat it was irrigated in June and July only.
b This is an estimate of depth of water used one October to test the value of fall irrigation.

It will be noticed that the largest amounts were used in June on alfalfa, grass, oats, barley, and wheat. Peas, rye, sugar beets, and potatoes received the most water in July. Usually irrigation does not begin at the experiment station until the middle of June, and practically no water is used in September. A little fall irrigation may be done in October to keep alfalfa and fruits from drying out during the winter. Usually those who irrigate large tracts of hay land necessarily turn their water off by the middle of July in order to harvest the crops, and although the amount flowing in the river is so small at this time, it generally proves sufficient for those crops which need irrigating in the latter part of the season. This condition, however, would effectually prevent the farmers changing their present system of cropping to any great extent. Should everyone plow up his meadow, which needs the early supply of water, and plant potatoes, that need late water, the shortness of the irrigating season and its transference to the latter part of summer would at once produce water famine and restrict irrigation to a few early priorities, while others would go without. There must necessarily be some adjustment between the time of supply in streams and the time of necessary use in irrigation.

THE IRRIGATING SEASON IN LAW.

The water law in Wyoming provides that:

Each appropriation shall be determined in its priority and amount by the time by which it shall have been made and the amount of water which shall have been applied for beneficial purposes: *Provided*, That such appropriator shall at no time be entitled

to the use of more water than he can make beneficial application of on the lands for the benefit of which the appropriations may have been secured, and the amount of any appropriation made by reason of an enlargement of distributing works shall be determined in like manner: *Provided*, That no allotment shall exceed one cubic foot per second for each seventy acres of land for which said appropriation shall be made.[1]

Section 2, on duty of water, in the law for the Northwest Territories of Canada, reads as follows:

> The duty of water, or the ratio between a given quantity of water and the amount of land it will irrigate, shall be one hundred acres for each cubic foot of water per second flowing constantly during the irrigating season, and division of the available water supply among applicants therefor shall be made upon the basis of this duty of water.

The Nebraska law covering the amount appropriated is an exact copy of the Wyoming law, and canal companies are required to furnish water from April 15 to November 1. In Colorado the law requires that beneficial use of the water shall be the basis on which allotments are made, and provides that ditch owners or companies who control water for pay must furnish a supply from April 1 to November 1 in each year.

In other places the amount of water which may be allotted an appropriator or the time it is to be furnished are not fixed. In Wyoming and Nebraska it is made the duty of the water commissioner to enforce economy in the use of water. The user is entitled to his full apportionment of 1 cubic foot for each 70 acres of land described in his certificate of appropriation during the time of minimum as well as maximum flow in the stream, provided he puts the water to beneficial use. In Canada, the term "irrigating season" is used but not defined.

CONTINUOUS FLOW AS A BASIS FOR APPROPRIATION.

Allowing a second-foot continuous flow for each 70 acres of land does not mean that the water is allowed to run continuously on the land for which it is appropriated. Only on native grass lands may a continuous flow for the season be used, and, as pointed out elsewhere, keeping the soil continuously saturated is bad practice. In actual use it is impossible to keep all the land wet all the time.

Flooding can not be done with much less than enough water to cover the land 3 inches deep, so that to flood 140 acres in twenty-four hours would require a head of over 18 second-feet. Under the most favorable conditions it is doubtful if an expert irrigator could flood 8 acres in twenty-four hours with a head of only 1 second-foot. On porous land which is dry a man would do well to thoroughly irrigate 1 or 2 acres a day. In irrigating small plats at the Wyoming Station consisting of from a fraction of an acre to 1 acre, a head of from 1 to over

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[1] Session Laws of Wyoming, 1890–91, chap. 8, sec. 25.

2 second-feet is ordinarily used, although it is sometimes as little as two or three tenths of a second-foot. Where the land is only partially irrigated, as with potatoes, by running the water in furrows, a very small head may sometimes be used; but in flooding sandy land little headway can be made with a flow of less than 2 or 3 second-feet. Irrigation is then necessarily intermittent, and in having a variety of crops, so that rotation in applying water can be practiced, the greatest use can be made of the supply.

In making allotments to the users of water it would not be possible to limit the time during which continuous flow of a second-foot for each 70 or 100 acres is supplied to the time during which each crop actually receives water. For the purpose of raising crops, water can not be so used, and the amount of water obtained by the appropriator under this system must depend on some arbitrary length of the season.

A cubic foot per second flowing continuously for ten days would cover 70 acres of land to a depth of 3.4 inches; flowing for fifty days it would cover the land 17 inches deep, in one hundred days 34 inches deep, and in a year 124 inches deep. The irrigator is clearly safe if he can define his own season and obtain in the few days his crops are to be supplied as much water for each 70 acres of land as a flow of 1 cubic foot per second for that season would furnish. He may need to use in less than fifteen days as much water on 70 acres of land as a cubic foot per second would supply in one hundred and thirty days. To do the irrigating in fifteen days would require a head of nearly 8.7 second-feet, flowing day and night. This illustration is taken from an actual case—that of oats on subsoiled land reported in the table giving water measurements on grain crops at Laramie in 1898. (See p. 33.) A little less than one-half acre of oats were irrigated twice, the irrigations being fourteen days apart. At the first irrigation the water flowed seven hours with a head of 2.01 feet, and at the second irrigation it flowed four and three-fourths hours with an average head of about 1.3 feet. The duty, allowing four months (May, June, July, and August), or one hundred and twenty-three days, for a continuous flow of 1 cubic foot per second, was 66.1 acres.

The Wyoming and Nebraska laws quoted at the beginning of this section are ingenious, and their application and value become apparent in connection with such a study as has been attempted here. The length of the irrigating season is not defined, leaving the amount of water which may be used by the appropriator sufficiently elastic to meet all requirements, though the irrigator would not be satisfied if it was necessary for him to attempt to irrigate so large an area with so small a head. Allotting water only for beneficial use on the land for which it is appropriated provides for the future reclamation of the greatest possible amount of the arid land with the available water supply. Future determinations of the facts relative to the beneficial

DIAGRAM SHOWING THE DISCHARGE OF THE LARAMIE RIVER AT WOODS LANDING, WYOMING, DURING THE IRRIGATION SEASONS OF 1896, 1897 AND 1898.

Diagram Showing the Time of Irrigation and Depth of Water Used on Different Crops at Laramie, Wyoming, in 1896.

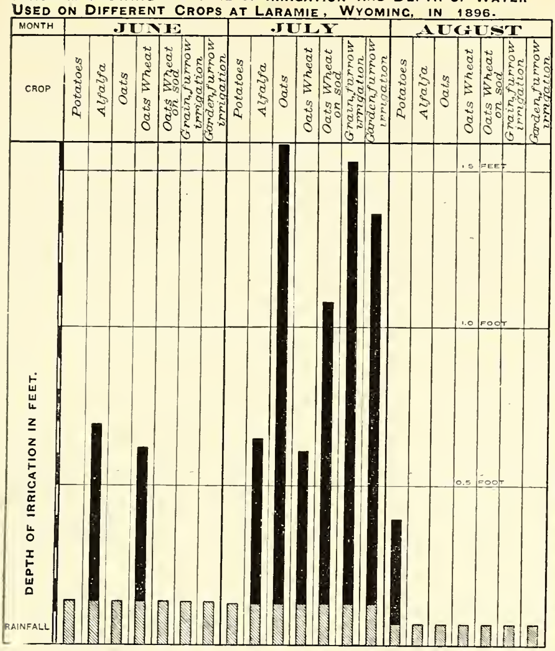


Diagram showing total depth of irrigation water and of rainfall at Laramie Wyo. during the irrigation season of 1896.

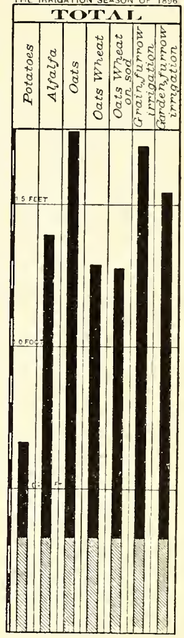


Diagram Showing the Time of Irrigation and Depth of Water Used on Different Crops at Laramie, Wyoming, in 1897.

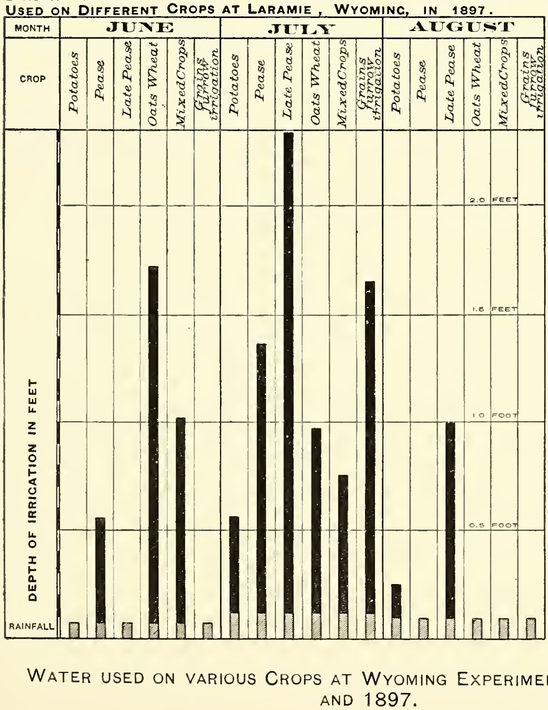
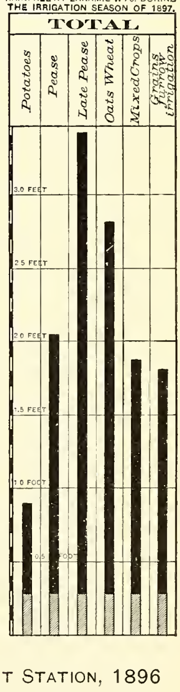


Diagram showing total depth of irrigation water and of rainfall at Laramie Wyo. during the irrigation season of 1897.



Water used on various Crops at Wyoming Experiment Station, 1896 and 1897.

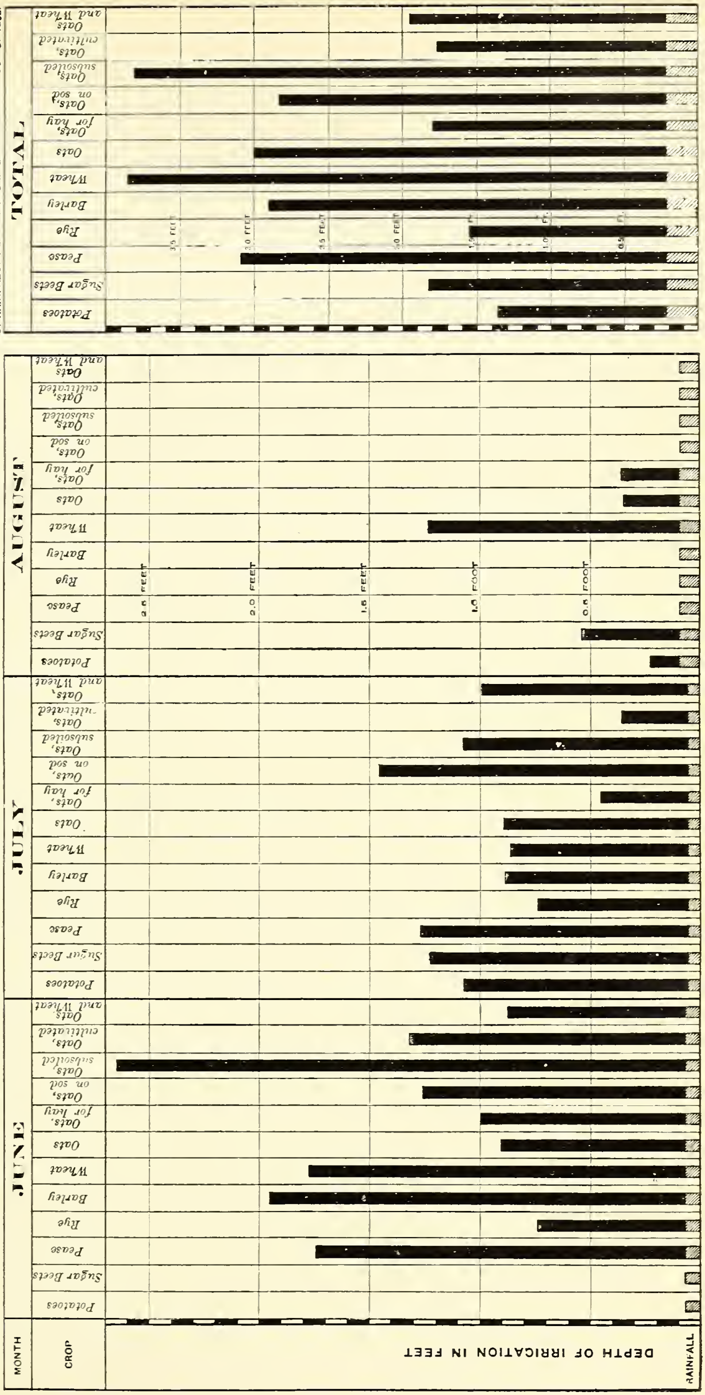


DIAGRAM SHOWING TOTAL DEPTH OF IRRIGATION WATER AND OF RAINFALL AT LARAMIE DURING IRRIGATION SEASON OF 1898.

DIAGRAM SHOWING TIME OF IRRIGATION AND DEPTH OF WATER USED ON DIFFERENT CROPS AT LARAMIE, WYO., IN 1898.

BLACK AREAS SHOW DEPTH OF IRRIGATION WATER. HATCHED AREAS SHOW DEPTH OF RAINFALL.

use of irrigation water can be applied without revision of the law, though it must be admitted that the present law does not cover the conditions actually obtaining in irrigation and that a continuous flow of 1 cubic foot per second for 70 acres of land may not be the best distribution of the supply.

A constant, uniform flow is a convenient method of dividing water from streams, but it is not an economical or satisfactory way of distributing from canals to users. Our supply is not available as a constant flow, and its use in irrigation is equally intermittent in quantity and time.

The actual instances of greatest supply at the time of greatest need or greatest use are undoubtedly rare, and the present method of appropriating an amount of water measured by a continuous flow for the land upon which it is to be used limits the amount of land which can be reclaimed to the supply in the stream at the time of its period of minimum flow during the irrigating season. If as much water is needed in July as in May, should five times as much water run down the streams in May its efficiency for irrigation purposes would not be greater than that measured by the July flow unless the water is stored till needed. Some years the Laramie River will supply enough water in May to irrigate 140,000 acres, allowing 1 cubic foot per second for 70 acres, while the supply in July would not be enough for 20,000 acres; consequently if the irrigator must have and can make beneficial use of his cubic foot per second for 70 acres in July, the natural flow of the Laramie River would not reclaim more than 20,000 acres.

In a recent publication Mr. Mead[1] says:

> There are two objections to making appropriations for irrigation a right to a perpetual flow of any definite volume of water. Such rights do not conform to the necessity of users or to the fluctuations in the flow of streams. No irrigator uses water all the time. In the States under consideration he does not use it one-half of the time. Even during the irrigating season the use is intermittent, and much greater in some months than in others. The holder of the right to a continuous flow, not needing it the greater part of the year, is continuously tempted to convert it into a speculative commodity by selling the surplus.

Reference to the tables on distribution of water throughout the season and to the accompanying charts will show the variations in the amount used each month and in the supply in streams, and represents an actual condition obtaining over a large part of the irrigated region. Plate V gives the supply furnished by the Laramie River in acre-feet for the years 1896, 1897, and 1898. There is a striking variation in the supply in different years, and the fluctuations in separate months during the irrigating season do not correspond with the necessities for crops. The maximum supply comes in May and the first half of June,

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[1] Water Rights on the Missouri River and its Tributaries. U. S. Dept. Agr., Office of Experiment Stations Bul. 58.

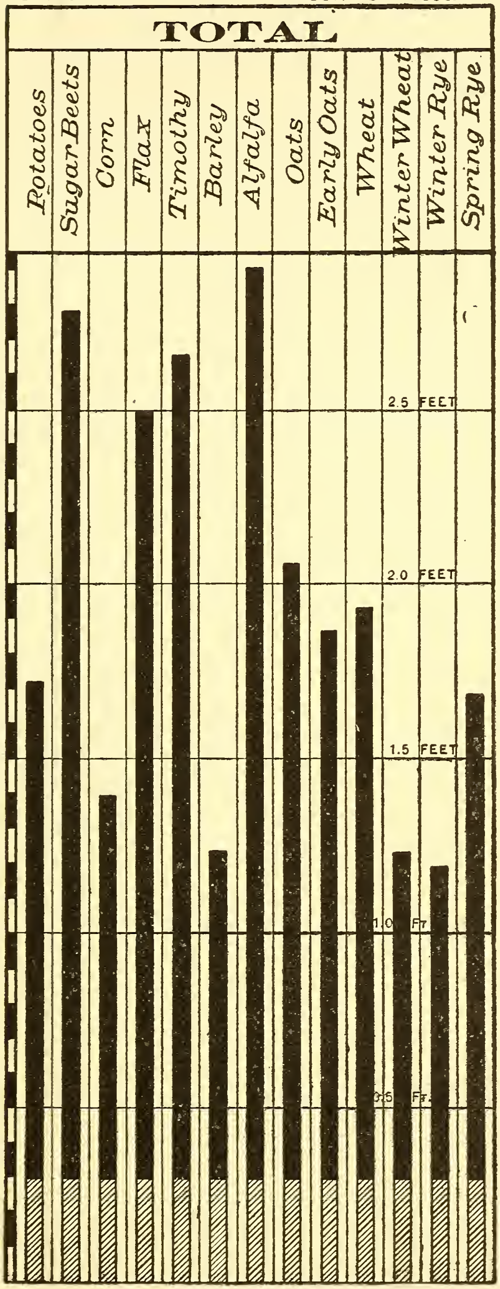
when the largest amount of water is used on native hay, but the maximum irrigation of other crops comes later in the season. Plate VI, representing the irrigation of principal crops at Laramie in 1896, shows a maximum use of water in July for grain, and in August for potatoes. This and the following plates (VII and VIII) represent the depth of water in feet applied in irrigation, which also indicates the number of acre-feet actually used each month on each acre for the crops named. Then if oats needed a depth of water of 1½ feet in July, 1897, the discharge of about 28,000 acre-feet in the river for that month would be sufficient to irrigate 18,666 acres; and if four-tenths of an acre-foot was needed for potatoes in August, the discharge of the river of about 5,000 acre-feet for the same month would be sufficient to irrigate 12,500 acres of potatoes, providing none was used for other crops.

In 1897 the fluctuations in the supply were greater than in 1896. Compared with the amounts used in irrigation that year as given in Plate VI, there was enough water in June to irrigate about 54,000 acres of oats and wheat, or about 90,000 acres of mixed crops, while in July the supply had fallen to only about enough for 19,000 acres of oats and wheat or 28,500 acres of mixed crops.

In 1898, comparing the flow given in Plate V with the use by irrigation the same year given in Plate VII, the supply in June was sufficient to irrigate from about 21,000 to 62,000 acres of oats, depending on the condition of the soil; over 32,000 acres of peas or wheat, and about 18,000 acres of barley. In July the discharge of the river would only be sufficient for from 4,000 to about 18,000 acres of oats, about 4,800 acres of peas, about 7,000 acres of wheat or barley, or nearly 6,000 acres of potatoes. In August, 1898, the supply fell so low that it was no more than sufficient for 3,000 acres of potatoes or 1,000 acres of wheat.

This discussion simply shows that where continuous flow is made the basis of appropriations to users, the amount of land which can be irrigated is determined by the supply at the time of minimum flow in the season, and the few early priorities which have sufficient water at that time are the only ones who can mature crops which require water late in the season. Those who have later priorities can irrigate only in the early part of the season, when there is sufficient flow in the stream to supply every one, and must consequently irrigate such crops as will mature without the late water. The man who has the first right and receives the late water may not be the one who wishes to raise potatoes, alfalfa, or other crops which require water at that time, in which case he has something he neither needs nor wants, while his neighbor who raises such crops must have the water or meet with disaster. This gives rise to a temptation to separate the water from the land in order to speculate in it, to sell to the highest bidder, or to let a useful commodity go to waste. Growing a variety of crops

DIAGRAM SHOWING TOTAL DEPTH OF IRRIGATION WATER AND DEPTH OF RAINFALL AT WHEATLAND DURING THE IRRIGATION SEASON OF 1893.



BLACK AREAS SHOW DEPTH OF IRRIGATION WATER. HATCHED AREAS SHOW DEPTH OF RAINFALL.

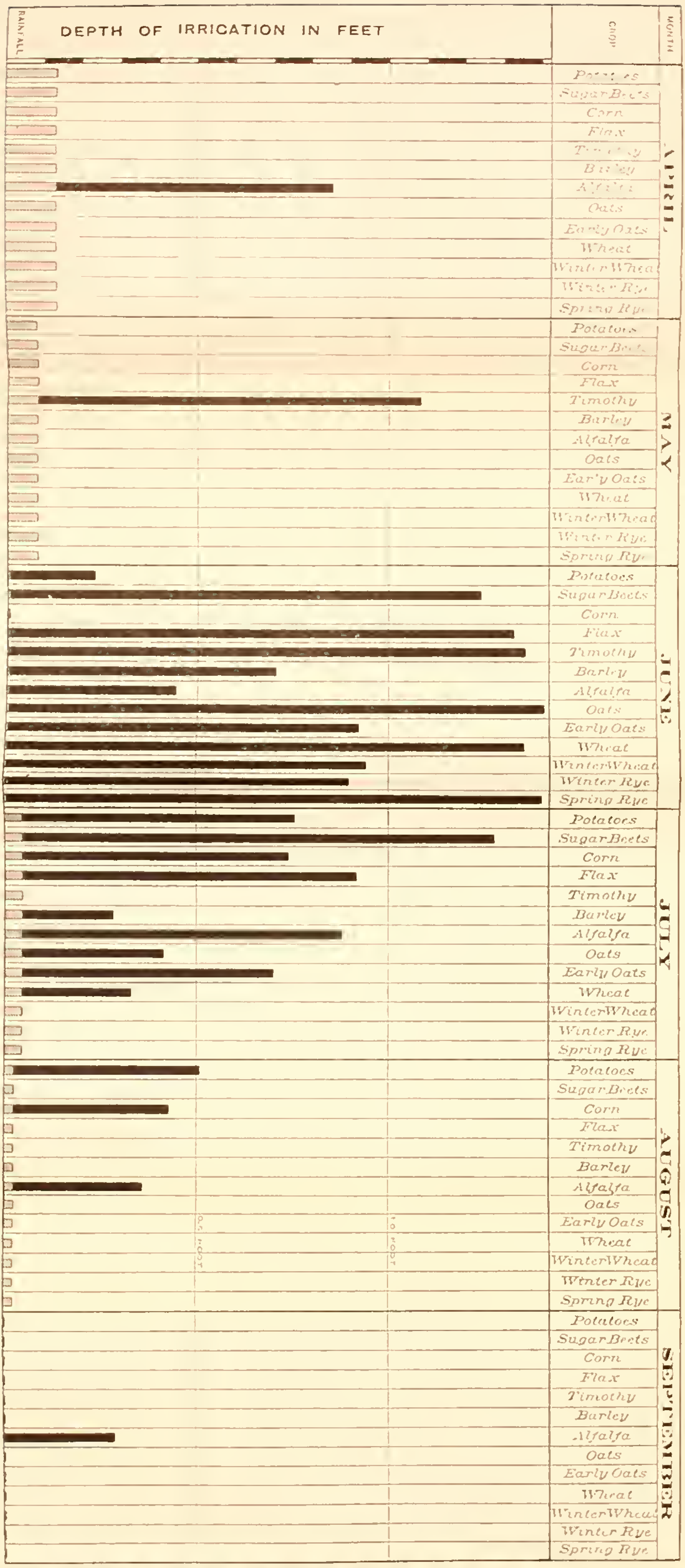


DIAGRAM SHOWING TIME OF IRRIGATION AND DEPTH OF WATER USED ON DIFFERENT CROPS AT WHEATLAND, WYO., IN 1893.

DIAGRAM SHOWING TOTAL DEPTH OF IRRIGATION WATER AND DEPTH OF RAINFALL AT WHEATLAND DURING THE IRRIGATION SEASON OF 1893.

lengthens out the irrigating season and enables the farmer to make better use of his continuous flow, but even this does not even up the difference between maximum supply and maximum use. The greatest necessity is storage until the water is needed. It would seem that the final solution must come through a system of storage combined with wise laws regarding appropriations which will insure the greatest use and economy of the whole water supply. The requirements of the land when used for the production of certain crops should be made the basis of allotments of water to users. There are in operation several ditch companies in the West which supply users with enough water in the season to cover their lands to a certain depth, and each farmer chooses the time through the season when each portion of the water is to be furnished. It would seem that such a system would eventually be followed by such adjustment of crops to the land and the water supply in different parts of the season as would bring about the greatest possible economy in the use of water.

GENERAL CONCLUSIONS.

In the region embraced in these studies the irrigation of native hay takes first place, both because it occupies the largest area of any single crop and because it is usually the first to be produced. There are several causes for this. It can be grown with less labor and expense than any other product, being already planted and requiring only irrigation and harvesting. It is one of the crops for which there is always an ample home market, the needs of the range stock business insuring this. It is furthermore a crop which is subject to few vicissitudes. Hail will not destroy it, and while a falling off in the water supply may greatly curtail the yield it will not result in an entire loss of the crop, as sometimes occurs with small grains and other cultivated products. The first attempt of the irrigator is usually, therefore, to make two blades of grass grow where one grew before. The growth of native hay, however, is the crudest and simplest form of irrigated agriculture. The return from the land is small and it is exceedingly wasteful of water. As both land and water become more valuable their use requires better methods and the growth of higher priced products. In the region under discussion irrigation is chiefly from small streams, and nearly all of the water supply which can be diverted is appropriated, but large volumes of water still run to waste in the larger rivers. It is along these that we must look for future development, but the utilization of this supply involves questions outside the scope of this investigation. These large rivers as a rule drain the mountain summits and have a more uniform flow than the small streams, as the snows which feed them melt slowly. The small streams, on the contrary, fluctuate so widely in

volume that it usually happens that more water runs to waste before irrigation of cultivated crops begins than is available for use in July, when the need for such crops is greatest. It is also an unfortunate circumstance that the most remunerative crops are those which require late irrigation. Sugar beets, potatoes, alfalfa, and orchards all require irrigation in August and September, which is the season of the least supply. These crops, while bringing large returns, require, as a rule, but little water, and their cultivation will secure a much higher average duty than now prevails; but to greatly extend the area of these products will involve comprehensive measures to increase through storage the present volume available for use in July, August, and September, because on three-fourths of the Wyoming streams there is now a scarcity in these months. If this shall not prove feasible, then the future extension of the areas now irrigated will come chiefly through the cultivation of crops which can be brought to maturity by water supplied before June 15. Among these, forage crops take first rank, as they can be irrigated as soon as water can be turned in ditches, and the stimulus given by a single watering will secure at least a partial crop. All these crops, however, are wasteful of water, and if they are to predominate in the extension of the reclaimed area, as will be necessary without storage, we may expect to see the average duty remain fully as low as at present.

The distinction between the abundant and hence cheap water supply of the first half of the irrigation season and the scanty and valuable supply in the latter half is made in appropriations and water-rights contracts in the irrigated districts of Europe, but as yet have not been considered in this State. We are not likely to continue to ignore this much longer. A second-foot of water for the month of August is worth ten to twenty times as much as the same volume for May, because it will make possible the irrigation of larger areas and the growing of high-priced products. It is this consideration which gives to water storage its significance and which will ultimately govern the number and cost of the works to provide for this purpose.

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